UNCLASSIFIED

SUMMARY TECHNICAL REPORT
OF THE
NATIONAL DEFENSE RESEARCH COMMITTEE

~~This document contains information affecting the national defense of the United States within the meaning of the Espionage Act, 50 U.S.C., 31 and 32, as amended. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.~~

~~This volume is classified [redacted] in accordance with security regulations of the War and Navy Departments because certain chapters contain material which was [redacted] the date of printing. Other chapters may have had a lower classification or none. The reader is advised to consult the War and Navy agencies listed on the reverse of this page for the current classification of any material.~~

[redacted]

UNCLASSIFIED

Manuscript and illustrations for this volume were prepared for publication by the Summary Reports Group of the Columbia University Division of War Research under contract OEMsr-1131 with the Office of Scientific Research and Development. This volume was printed and bound by the Columbia University Press.

Distribution of the Summary Technical Report of NDRC has been made by the War and Navy Departments. Inquiries concerning the availability and distribution of the Summary Technical Report volumes and microfilmed and other reference material should be addressed to the War Department Library, Room 1A-522, The Pentagon, Washington 25, D. C., or to the Office of Naval Research, Navy Department, Attention: Reports and Documents Section, Washington 25, D. C.

Copy No.
55

This volume, like the seventy others of the Summary Technical Report of NDRC, has been written, edited, and printed under great pressure. Inevitably there are errors which have slipped past Division readers and proofreaders. There may be errors of fact not known at time of printing. The author has not been able to follow through his writing to the final page proof.

Please report errors to:

JOINT RESEARCH AND DEVELOPMENT BOARD
PROGRAMS DIVISION (STR ERRATA)
WASHINGTON 25, D. C.

A master errata sheet will be compiled from these reports and sent to recipients of the volume. Your help will make this book more useful to other readers and will be of great value in preparing any revisions.

[redacted]

UNCLASSIFIED

SUMMARY TECHNICAL REPORT OF DIVISION 4, NDRC

VOLUME 3

SUMMARY, PHOTOELECTRIC FUZES AND MISCELLANEOUS PROJECTS

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
VANNEVAR BUSH, DIRECTOR

NATIONAL DEFENSE RESEARCH COMMITTEE
JAMES B. CONANT, CHAIRMAN

DIVISION 4
ALEXANDER ELLETT, CHIEF

WASHINGTON, D. C., 1946

[redacted]

UNCLASSIFIED

NATIONAL DEFENSE RESEARCH COMMITTEE

James B. Conant, *Chairman*
Richard C. Tolman, *Vice Chairman*

Roger Adams — Army Representative[1]
Frank B. Jewett — Navy Representative[2]
Karl T. Compton — Commissioner of Patents[3]

Irvin Stewart, *Executive Secretary*

[1] *Army representatives in order of service:*
Maj. Gen. G. V. Strong
Maj. Gen. R. C. Moore
Maj. Gen. C. C. Williams
Brig. Gen. W. A. Wood, Jr.
Col. L. A. Denson
Col. P. R. Faymonville
Brig. Gen. E. A. Regnier
Col. M. M. Irvine
Col. E. A. Routheau

[2] *Navy representatives in order of service:*
Rear Adm. H. G. Bowen
Capt. Lybrand P. Smith
Rear Adm. J. A. Furer
Rear Adm. A. H. Van Keuren
Commodore H. A. Schade

[3] *Commissioners of Patents in order of service:*
Conway P. Coe
Casper W. Ooms

NOTES ON THE ORGANIZATION OF NDRC

The duties of the National Defense Research Committee were (1) to recommend to the Director of OSRD suitable projects and research programs on the instrumentalities of warfare, together with contract facilities for carrying out these projects and programs, and (2) to administer the technical and scientific work of the contracts. More specifically, NDRC functioned by initiating research projects on requests from the Army or the Navy, or on requests from an allied government transmitted through the Liaison Office of OSRD, or on its own considered initiative as a result of the experience of its members. Proposals prepared by the Division, Panel, or Committee for research contracts for performance of the work involved in such projects were first reviewed by NDRC, and if approved, recommended to the Director of OSRD. Upon approval of a proposal by the Director, a contract permitting maximum flexibility of scientific effort was arranged. The business aspects of the contract, including such matters as materials, clearances, vouchers, patents, priorities, legal matters, and administration of patent matters were handled by the Executive Secretary of OSRD.

Originally NDRC administered its work through five divisions, each headed by one of the NDRC members. These were:

Division A—Armor and Ordnance
Division B—Bombs, Fuels, Gases, & Chemical Problems
Division C—Communication and Transportation
Division D—Detection, Controls, and Instruments
Division E—Patents and Inventions

In a reorganization in the fall of 1942, twenty-three administrative divisions, panels, or committees were created, each with a chief selected on the basis of his outstanding work in the particular field. The NDRC members then became a reviewing and advisory group to the Director of OSRD. The final organization was as follows:

Division 1—Ballistic Research
Division 2—Effects of Impact and Explosion
Division 3—Rocket Ordnance
Division 4—Ordnance Accessories
Division 5—New Missiles
Division 6—Sub-Surface Warfare
Division 7—Fire Control
Division 8—Explosives
Division 9—Chemistry
Division 10—Absorbents and Aerosols
Division 11—Chemical Engineering
Division 12—Transportation
Division 13—Electrical Communication
Division 14—Radar
Division 15—Radio Coordination
Division 16—Optics and Camouflage
Division 17—Physics
Division 18—War Metallurgy
Division 19—Miscellaneous
Applied Mathematics Panel
Applied Psychology Panel
Committee on Propagation
Tropical Deterioration Administrative Committee

FOREWORD

As events of the years preceding 1940 revealed more and more clearly the seriousness of the world situation, many scientists in this country came to realize the need of organizing scientific research for service in a national emergency. Recommendations which they made to the White House were given careful and sympathetic attention, and as a result the National Defense Research Committee [NDRC] was formed by Executive Order of the President in the summer of 1940. The members of NDRC, appointed by the President, were instructed to supplement the work of the Army and the Navy in the development of the instrumentalities of war. A year later, upon the establishment of the Office of Scientific Research and Development [OSRD], NDRC became one of its units.

The Summary Technical Report of NDRC is a conscientious effort on the part of NDRC to summarize and evaluate its work and to present it in a useful and permanent form. It comprises some seventy volumes broken into groups corresponding to the NDRC Divisions, Panels, and Committees.

The Summary Technical Report of each Division, Panel, or Committee is an integral survey of the work of that group. The report of each group contains a summary of the report, stating the problems presented and the philosophy of attacking them, and summarizing the results of the research, development, and training activities undertaken. Some volumes may be "state of the art" treatises covering subjects to which various research groups have contributed information. Others may contain descriptions of devices developed in the laboratories. A master index of all these divisional, panel, and committee reports which together constitute the Summary Technical Report of NDRC is contained in a separate volume, which also includes the index of a microfilm record of pertinent technical laboratory reports and reference material.

Some of the NDRC-sponsored researches which had been declassified by the end of 1945 were of sufficient popular interest that it was found desirable to report them in the form of monographs, such as the series on radar by Division 14 and the monograph on sampling inspection by the Applied Mathematics Panel. Since the material treated in them is not duplicated in the Summary Technical Report of NDRC, the monographs are an important part of the story of these aspects of NDRC research.

In contrast to the information on radar, which is of widespread interest and much of which is released to the public, the research on subsurface warfare is largely classified and is of general interest to a more restricted group. As a consequence, the report of Division 6 is found almost entirely in its Summary Technical Report, which runs to over twenty volumes. The extent of the work of a Division cannot therefore be judged solely by the number of volumes devoted to it in the Summary Technical Report of NDRC; account must be taken of the monographs and available reports published elsewhere.

The program of Division 4 in the field of electronic ordnance provides an excellent example of the manner in which research and development work by a civilian technical group can complement and supplement work done by the Armed Services. The greatest responsibility of Division 4, under the leadership of Alexander Ellett, was to undertake the development of proximity fuzes for nonrotating or fin-stabilized missiles, such as bombs, rockets, and mortar shells.

Early work on fuzes of various types indicated that those operating through the use of electromagnetic waves offered the most promise; the eventual device depended on the doppler effect, combining the transmitted and received signals to create a low frequency beat which triggered an electronic switch. During the last phases of the war against Japan, approximately one-third of all the bomb fuzes used by carrier-based aircraft were proximity fuzes. For improving the accuracy of bombing operations, the Division developed the toss bombing technique, by which the effect of gravity on the flight path of the missile is estimated and allowed for. The success of this technique is demonstrated by its combat use, when a circle of probable error as low as 150 feet was obtained.

The Summary Technical Report of Division 4 was prepared under the direction of the Division Chief and has been authorized by him for publication. We wish to pay tribute to the enterprise and energy of the members of the Division, who worked so devotedly for its success.

Vannevar Bush, Director
Office of Scientific Research and Development

J. B. Conant, Chairman
National Defense Research Committee

FOREWORD

The primary program of Division 4, NDRC, was the development of proximity fuzes for bombs, rockets, and trench mortar projectiles. The National Bureau of Standards provided facilities and personnel for the Division Central Laboratories and the Division (or its predecessor, Section E of Division A) served as the principal liaison between NDRC and the National Bureau of Standards. The photoelectric fuze project formed a considerable part of the Division program during the first half of the war; a summary of work on that project comprises the major part of the present volume. Work on photoelectric fuzes was initiated in the fall of 1940 by Section T at the Department of Terrestrial Magnetism under the able direction of L. R. Hafstad. In the summer of 1941, the project was transferred from Section T to Section E, and the work continued at the National Bureau of Standards. Many of the project personnel were also transferred, including, for a short period, Dr. Hafstad. After the project was well established in Section E, he returned to Section T, and Joseph E. Henderson carried on as project leader. The maintenance of effective liaison with the Army Ordnance Department is due largely to Colonel H. S. Morton, whose intelligent criticism and suggestions based on sound technical knowledge contributed much of value to the program.

The development of photoelectric fuzes was undertaken because it was thought that a fuze of this type could be gotten into production more quickly than radio proximity fuzes. Actually this proved not to be the case, the radio fuze development (which is described in Volume 1 of Division 4) reaching the production point just as soon as the photoelectric fuze, so that the latter never went beyond the initial model. A further important consideration in the development of photoelectric fuzes was the plan of the Army Ordnance Department to provide an ammunition reserve of more than one basic type of proximity fuze for possible emergency use. The production of the T–4 photoelectric fuze was in fulfillment of this objective.

The present volume also includes an overall summary chapter of Division 4's work, together with descriptions of work on projects later transferred from Division 4 and of work on several minor projects. Of the latter, the most important is the magnetic field extrapolating machine, which was effectively used by the Navy in connection with degaussing. The utility and feasibility of this device was first pointed out by G. Breit. The realization of the device in a practical form was due to J. W. M. DuMond, with the assistance of the Bell Telephone Laboratories in connection with the design of the production model.

Alexander Ellett
Chief, Division 4

PREFACE

The projects dealt with in this volume (other than the Summary Chapter) are, generally, terminated or completed projects, in the sense that Division 4 was not engaged in active work on any of them (except the T–25 Project, Section 9.2) when World War II ended. In contrast, very active programs were under way on radio proximity fuzes (Volume 1) and on the toss technique (Volume 2). Responsibility for further development on these two projects was assumed near the end of the war by the Army and the Navy.

Work on photoelectric fuzes, which occupied a prominent part in the Division program for nearly three years, is summarized in Chapters 3 to 8, inclusive, of this volume. Work on general fuze problems is presented in Chapter 2, which serves as a summary of the proximity fuze program of the Division inasmuch as the relative merits of various types of proximity fuzes are compared therein. Other miscellaneous projects of the Division are summarized in Chapter 9.

With the notable exception of the photoelectric fuze work, fairly complete termination reports were written on most of the projects covered in this volume. These terminating reports, which are included in the bibliographies, have been appreciably condensed for inclusion in this volume. In the case of the photoelectric fuze work, no overall termination report was written, although work on the project ended in October 1943. The urgency of other projects in the Division (radio fuzes and toss bombing) prevented the assignment of personnel to such report writing during the war. Hence Chapters 3 to 8 of this volume represent the only overall summary of this once very comprehensive project.

Credit is due Alex Orden for organizing the presentation of the photoelectric fuze work, as well as for writing three of the six chapters on the subject. Other authors are named in the table of contents and in footnotes to the chapter or section headings. Where authorship is not specified, the material was prepared by the editor.

Photographs in this volume were made by Theodore C. Hellmers, of the National Bureau of Standards, unless credit is otherwise indicated. Drawings and graphs were prepared by the Drafting Group of the Ordnance Development Division of the National Bureau of Standards under the immediate supervision of E. W. Hunt.

Considerable thanks are due R. L. Eichberg and Betty Hallman, of the National Bureau of Standards, for valuable assistance in the review and assembly of final manuscript, and to Henrietta Leiner and Cecilie Smolen of the same organization, for the preparation of the bibliography.

A. V. Astin
Editor

CONTENTS

Chapter 1

SUMMARY OF WORK OF DIVISION 4

1.1 SCOPE

The work of Division 4, National Defense Research Committee [NDRC], was concerned primarily with problems in electronic ordnance. This involved the development of ways and means of increasing the effectiveness of weapons through the application of modern electronic techniques. Weapon effectiveness depends, in general, on three factors which are subject to control: (1) properties of the missile and its contents, (2) methods of aiming or directing the missile to its target, and (3) methods of controlling the detonation of the missile with respect to the target. Electronic ordnance is concerned primarily with the second and third factors, and remarkable advances in these fields were achieved during the period of World War II. The field of electronic ordnance, as defined, embraces not only the major work of Division 4, but also the work of many other NDRC divisions.

Within the field of electronic ordnance, the work of Division 4 was concerned with proximity (variable time) [VT] fuzes for nonrotating or fin-stabilized missiles, such as bombs, rockets, and trench mortar shells, and with bomb directors. The work on these projects is summarized in Sections 1.2 and 1.3. The initiation of the bomb director project was closely related to problems pertaining to the use of VT fuzes. It was evident that, in order to bring bombs close enough to airborne targets for proximity action to be effective, the accuracy of bombing operations had to be increased. This need led to the inception of the toss bombing technique, which is described in Section 1.3. A similar problem was encountered by Section T, OSRD, in their work on proximity fuzes for rotating (spin-stabilized) projectiles. In order for the VT shell fuzes to be effective in antiaircraft fire, methods of aiming had to be improved. This led to Section T's participation in fire control development.

As inferred in the preceding paragraph, responsibility for the development of proximity fuzes was shared by Division 4 and Section T, with the former handling fuzes for fin-stabilized missiles, and the latter, fuzes for spin-stabilized missiles. This division of responsibility, which was made for reasons of expediency and efficiency, proved very logical. The basic operating principles of the proximity fuzes developed were quite simple and were similar for both Division 4 and Section T fuzes. The major problem lay in adapting the design to the conditions of Service use and to a form which could be produced quickly in large quantities. In this, there proved to be basic differences in the fuzes for rotating and nonrotating missiles. These differences appeared in general mechanical layout and design, in the arming and safety features, and in the method of obtaining electrical power to operate the fuze. Taking the latter problem as an example, shell fuzes utilized the spin of the missile as an activating force for the power supply, whereas bomb fuzes were powered by electrical energy converted from mechanical energy, utilizing the airflow past the nose of the bomb. Still another difference between the power supplies for bomb and shell fuzes lay in the requirements for performance at very low temperatures. Bomb fuzes were required to perform reliably when cooled to the very low temperatures encountered by high-altitude bombers. An outstanding feature of most of the fuzes developed by Division 4 was a wind-driven electric generator which enabled the fuze to operate properly when subjected to temperatures as low as —40 F.

In addition to work on proximity fuzes and bomb directors, Division 4 pursued a number of other important, but less extensive, projects. Some of these were related to fuze work; others were undertaken because of the availability of specialized personnel or facilities at Division 4's Central Laboratories at the National Bureau of Standards. The miscellaneous activities are listed in Section 1.4.

The Summary Technical Report of Division 4 has been prepared in three volumes, as follows: Volume 1, on radio proximity fuzes for bombs, rockets, and trench mortar shells; Volume 2, on bomb, rocket, and torpedo tossing; and Volume 3, containing, in addition to this overall summary chapter, descriptions of work on nonradio fuzes (particularly photoelectric fuzes) and other miscellaneous ordnance items. The introductory chapters of Volumes 1 and

2 contain rather complete summaries of the respective projects. These chapters have been abstracted for presentation in Sections 1.2 and 1.3, which follow.

1.2 RADIO PROXIMITY [VT] FUZES

1.2.1 Selection of the Radio Method

Proximity fuzes are intended to detonate missiles automatically upon approach to a target and at such a position along the flight path of the missile as to inflict maximum damage to the target. Various methods of obtaining proximity operation against a target were investigated: electrostatic, acoustic, optical, and radio. The relative merits of these methods are discussed in Chapter 2 of this volume. Prime considerations for a proximity fuze were reliability and simplicity. The former was necessary to insure performance under various stringent Service conditions, and the latter, to allow the fuze to be contained in a small volume and to be produced quickly in large quantities. Following initial exploratory investigations, two types of fuzes, optical (photoelectric) and radio, were selected for intensive development. The photoelectric method was selected because it appeared as a relatively easy approach to the proximity fuze problem, although the fuzes would be limited to daytime use, unless light sources were provided. The radio method appeared to be more complicated, but it afforded opportunity for reliable performance not only 24 hours a day but under a much wider variety of other conditions than were possible with the photoelectric fuze. The two methods were pursued in parallel until it was definitely established that radio proximity fuzes could be produced to fulfill all requirements. When this stage of development was reached, work on photoelectric fuzes was terminated (October 1943), and the radio method was prosecuted even more vigorously than before. A brief summary of the achievements in the photoelectric program is given in Chapter 3 of this volume, and a more detailed presentation in Chapters 4 to 8, inclusive.

1.2.2 How a Radio Proximity Fuze Operates

Among various possible types of *radio* proximity fuzes, an active-type fuze operating on the doppler effect was selected as being the most promising method.[a]

In a doppler-type fuze, the actuating signal is produced by the wave reflected from a target moving with respect to the fuze. The frequency of the reflected wave differs from that of the transmitted wave, because of the relative velocity of fuze and target. The interference it creates with the transmitter results in a low-frequency beat caused by the combination of the transmitted and reflected frequencies. The low-frequency signal can be used to trigger an electronic switch. Selective amplification of the low-frequency signal is generally necessary.

The principal elements of a radio proximity fuze are shown in block diagram form in Figure 1.

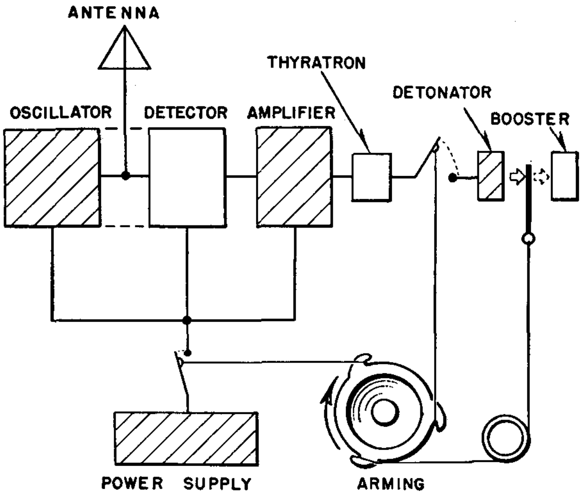


FIGURE 1. Block diagram showing principal components of radio proximity fuze.

Operation of the fuze occurs when the output signal from the amplifier reaches the required amplitude to fire the thyratron. For a given orientation of the fuze and target, the amplitude of the target signal produced in the oscillator-detector circuit is a function of the distance between the target and the fuze. Hence, by proper settings for the gain of the amplifier and the holding bias on the thyratron, the distance of operation may be controlled. Distance,

[a] See Chapter 2 of this volume for a further discussion of active and passive fuzes, and Division 4, Volume 1, Chapter 1 for a discussion of other possible types of radio fuzes. Briefly, an active-type radio fuze includes both transmitting and receiving stations, whereas a passive-type fuze contains a receiving station only. Obviously, a passive-type radio fuze would require an auxiliary transmitter as part of the fire control equipment.

however, is not the only factor which requires consideration. Orientation or aspect is very important, particularly against aircraft targets, since operation should occur at that point on the trajectory when the greatest number of fragments will be directed toward the target.

For most missiles, the greatest number of fragments are directed upon detonation approximately at right angles to the axis of the missile. For trajectories which would normally pass by the target without intersecting it, there will be optimum chance of damage if detonation of the missile occurs when the target is in the direction of greatest fragmentation density. However, for trajectories which would intersect the target, the missile should come as close to the target as possible before detonation. Hence the basic requirements for directional sensitivity of a proximity fuze for antiaircraft use are: (1) the sensitivity should be a maximum in the direction corresponding to maximum lateral fragmentation density of the missile, and (2) the sensitivity should be a minimum along the axis of the missile. Directional sensitivity of this type can be obtained by using the missile as an antenna, with the axis of the missile corresponding to the axis of the antenna. With the fuze in the forward end of the missile, such antennas are excited by means of a small electrode, or cap, on the nose of the fuze. Additional control over the sensitivity pattern of the fuze is possible by means of the amplifier gain characteristic.

For use against surface targets, proximity fuzes are designed for an optimum height of burst, depending on the nature of the target and the properties of the missile. These optimum heights of function vary from 10 to 70 ft for fragmentation and blast bombs and are of the order of a few hundred feet for chemical warfare bombs.

With a fuze intended for ground approach operation, it is desirable to have maximum sensitivity along the axis of the bomb. A short dipole antenna mounted in the fuze transversely to the bomb's axis gives such sensitivity.

It was also found that fairly good ground approach performance could be obtained from fuzes with axial antennas by designing the amplifiers to compensate for the appreciable decrease in radiation sensitivity in the forward direction. For example, steep angles of approach generally mean high approach velocities with higher doppler frequencies. Thus a loss in radiation sensitivity with steep approach can be compensated by an increase in amplifier gain for the higher doppler frequencies.

A miniature triode is used for the oscillator in the fuze, and a pentode for the amplifier. Some fuzes use separate detector circuits with a tiny diode to provide the required rectification. A miniature thyratron serves as the triggering agent, and a specially developed electric detonator initiates the explosive action.

Energy for powering the electronic circuit is obtained, in the later fuze models, from a small electric generator. This is driven by a windmill in the airstream of the missile. A rectifier network and voltage regulator are also essential parts of the power supply.

The arming and safety features of the radio proximity fuzes are closely tied in with the power supply. This is a natural procedure since an electronic device is inoperative until electric energy is supplied. Arming a radio proximity fuze (generator type) consists of the following operations: (1) either removal of an arming wire which frees the windmill, allowing it to turn in the airstream (bomb fuzes), or actuation of a setback device freeing the drive shaft of the generator, allowing it to turn (rocket and mortar shell fuzes), (2) operation of the generator to supply energy to the fuze circuits, (3) connection of the electric detonator into the circuit after a predetermined number of turns of the vane corresponding to a certain air travel, and (4) removal of a mechanical barrier between the detonator and booster, prior to which explosion of the detonator would not explode the booster. Generally, operations (3) and (4) occur simultaneously by motion of the same device. These arming operations are indicated in the diagram in Figure 1.

Additional safety is provided by the fact that unless the generator of the fuze is turning rapidly the fuze is completely inoperative. A minimum airspeed of approximately 100 mph is required to start the generator turning.

Sectioned models of two types of generator-powered radio fuzes for bombs are shown in Figures 2 and 3. The fuze in Figure 2 uses the bomb as an antenna. It is a T–50 type fuze, frequently referred to as a ring-type fuze. The fuze in Figure 3 carries its own transversely mounted antenna. It is a T–51 fuze, frequently referred to as a bar-type fuze.

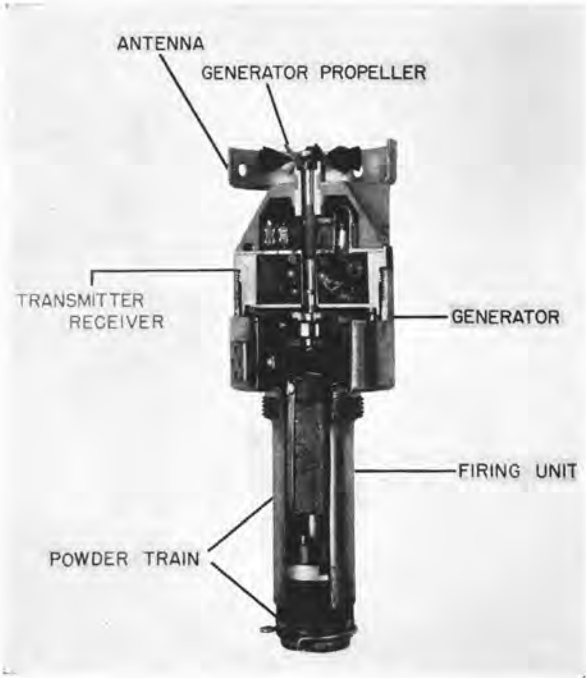


FIGURE 2. Cutaway of ring-type, radio, bomb fuze (T-91E1).

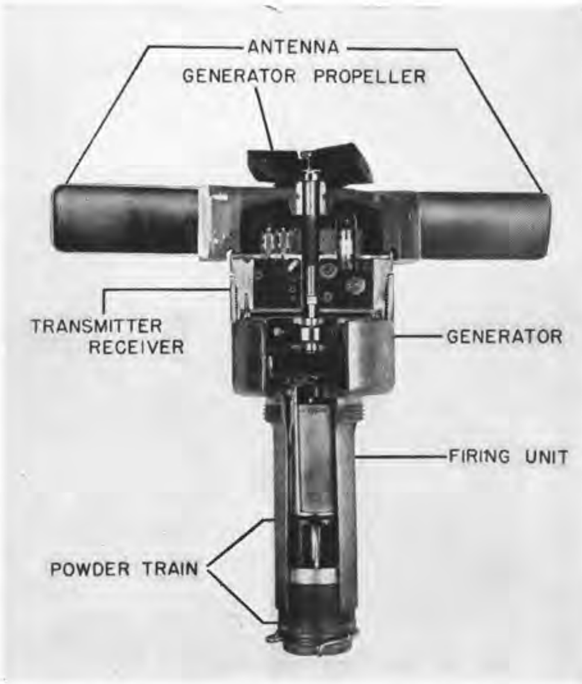


FIGURE 3. Cutaway of bar-type, radio, bomb fuze (T-51).

1.2.3 Production of Radio Proximity Fuzes

The course of the development of radio proximity fuzes for fin-stabilized missiles and the actual nature of the devices placed in production for Service use were influenced by many factors other than fundamental technical considerations. Time and expediency had a major influence on all designs. In order to have fuzes available for use as soon as possible, tooling for large production was frequently started before development was complete. This meant that, when changes in design became necessary or desirable, the extent of such changes was largely controlled by the amount of retooling required or the delay which would be caused in production. Furthermore, equipment design could not require components which would take too long to acquire in the necessary quantity, nor could overelaborate and time-consuming production techniques be considered.

Specific Service requirements varied as the course of World War II changed, and, because of the pressing demand for speed, fuze designs for the new requirements made much more use of the tools and techniques employed in preceding models than if production had started out fresh. For example, early in World War II the greatest urgency was for antiaircraft weapons, and stress was placed on fuzes for both bombs and rockets for this purpose. When the Allies acquired undisputed air superiority, the major proximity fuze requirements were shifted to the ground approach operation. Thus the T–50 type bomb fuze, which employs the axial radio antenna, ideal for antiaircraft use and initially designed for that purpose, was adapted to ground approach use. The T–51 fuze, which employs the transverse antenna specifically developed for ground approach use, was used much less extensively for this application because its initial lower priority made it available later in the war.

After the operation of a fuze design was found satisfactory by laboratory and field tests, it was necessary to determine its practicability for mass production. Pilot construction lines were used for this purpose, and it was the policy of Division 4 to require the construction of about 10,000 pilot line fuzes with suitable performance characteristics before releasing a design to the Armed Services. Usually the tools developed for the pilot line work were used also for final production. Large-scale procurement was handled by the Services, but Division 4 participated in many phases of it, although largely in an advisory capacity.

The radio proximity fuzes developed by Division 4 to the stage of large-scale production are as follows:

M–8 Rocket Fuzes. T–5, an antiaircraft battery-powered fuze for the 4.5-in. M–8 rocket. This fuze is shown in Figure 4. Approximately 370,000 of these fuzes were procured by the Army.

FIGURE 4. T–5 radio proximity fuze. Right view: fuze ready for loading in rocket. Middle view: assembled fuze (ready for screwing into housing and booster container, left). Middle view shows three principal components of fuze electronic assembly or nose (top), battery (middle), and safety and arming switch (bottom).

T–6, a ground approach fuze, for use as an artillery weapon on the 4.5-in. M–8 rocket. This fuze is a variation of the T–5 fuze, having a longer arming time (about 6 sec compared to 1.0 sec) and no self-destruction element. It is identical in exterior appearance with the T–5 fuze. Approximately 300,000 of the T–5 fuzes were converted to T–6 fuzes after completion.

Bomb Fuzes. T–50E1, a generator-powered ground approach fuze, for use primarily on the 260-lb M–81 fragmentation bomb, the 100-lb M–30 general purpose [GP] bomb, and the 2,000-lb M–66 general purpose bomb. This fuze, which uses the bomb as a radio antenna, was planned for air-to-air use when development started, but was changed to ground approach application before development was completed. This fuze was set to arm after 3,600 ft of air travel. In appearance it is very similar to the T–91 fuze shown in Figure 2.

T–50E4 is similar to the T–50E1 except that its transmitter operates in a different frequency band, giving optimum performance on the 500-lb M–64 and the 1,000-lb M–65 general purpose bombs. Approximately 130,000 T–50E4 and T-90 fuzes were procured by the Army.

T–89, an improved T–50E1 type fuze, giving more uniform burst heights. It also differs from T–50E1 type fuzes in that arming setting can be checked more readily in the field. Approximately 140,000 T–50E1 and T–89 fuzes were procured by the Services. This fuze is similar in appearance to the T–91 fuze, shown in Figure 2.

T–91 (later designation M–168), a variation of the T–89, developed specifically for low-altitude bombing to meet a naval requirement of higher burst heights than the T–89. This fuze is set to arm after 2,000 ft of air travel. Approximately 120,000 T–91 fuzes were produced. This is the fuze shown in Figure 2.

T–92, a variation of the T–90, developed to meet the same performance requirements as the T–91 of higher burst heights in low-altitude bombing. It is similar in appearance to the T–91 fuze. Approximately 70,000 of these fuzes were produced.

T–51 (later designation M–166), a generator-powered bomb fuze with a transverse antenna, for ground approach use on all general purpose, fragmentation, and blast bombs of 100-lb size or larger. Burst heights with the T–51 are generally higher than with T–50 type fuzes. This fuze was set to arm after 3,600 ft of air travel. Approximately 350,000 of these fuzes were procured by the Services. This fuze is shown in Figure 3.

Later Rocket Fuzes. T–30 (Navy designation Mark 171), a generator-powered rocket fuze for air-to-air use, particularly on the Navy's high-velocity aircraft rockets [HVAR] and 5-in. aircraft rockets [AR]. This fuze is physically very similar to the T–91 bomb fuze and only slightly different electrically. Its arming system is different in that the acceleration of the rocket is essential to its operation. This fuze had just reached a production rate of 10,000 per month at the end of World War II.

T–2004 (Navy designation Mark 172), a generator-powered rocket fuze for ground approach use. Similar to the T–30 but somewhat less sensitive and

[redacted]

has a longer arming time. Approximately 110,000 of these fuzes were procured by the Services.

Trench Mortar Fuzes. (Shown in Figure 5.) T–132, a generator-powered ground approach fuze, for use on the 81-mm trench mortar shell. This fuze

FIGURE 5. Radio proximity fuzes for trench mortar shells. These are, from left to right, T–132, T–171, and T–172. The first two use the missile as an antenna, and the last carries its own antenna in the form of a loop.

uses the body of the shell as an antenna. It also incorporates a novel production technique, i.e., printed or stenciled electric circuits. Tools were being set up for a production rate of approximately 100,000 fuzes per month when World War II ended.

T–171, a generator-powered, ground approach, mortar shell fuze, similar to the T–132, except that it employs the more standard circuit-assembly techniques. Tools were being set up for a production rate of about 125,000 per month when World War II ended.

T–172, a generator-powered, ground approach, mortar shell fuze with a loop antenna. This antenna has essentially the same directional properties as the transverse antenna of the T–51 bomb fuze. Tools were being set up for a production rate of about 250,000 fuzes per month.

Figure 6 shows several typical missiles fuzed with radio proximity fuzes.

1.2.4 Evaluation of Radio Proximity Fuzes

Although the final answer on the effectiveness of a new military weapon is supplied by its performance in battle, the best quantitative measure of relative effectiveness under controlled conditions can be obtained from carefully planned effect-field trials. Evaluation tests which have been carried out on radio proximity fuzes can be grouped into the following categories: (1) evaluation of conformance to requirements, and (2) evaluation as a weapon.

1. *Evaluation of conformance to requirements.* Based extensively on production acceptance testing, the reliability of the radio proximity fuzes for bombs and rockets was about 85 per cent; that is, 85 per cent of the fuzes would be expected to function on the target as required. Of the remainder, about 10 per cent could be expected to function before reaching the target (random bursts) and 5 per cent not to function at all. The 10 per cent or so random functions were distributed along the trajectory between the end of the arming period and the target. In many thousands of tests, no fuze functions were observed before the end of the arming period.

FIGURE 6. Radio proximity fuzes assembled on missiles. Left, Mr. Harry Diamond, Chief of Ordnance Development Division, National Bureau of Standards (Division 4 central laboratories) and, right, Dr. Alexander Ellett, Chief, Division 4, NDRC. Fuzes and missiles are, left to right, T–132 fuze on 81-mm trench mortar shell (in Mr. Diamond's hands); T–2004 fuze on HVAR rocket; T–2005 (experimental) fuze on HVAR; T–51 fuze on M–81 bomb; and T–91 fuze on M–64 bomb. A T–132 mortar shell fuze is in Dr. Ellett's hand.

Reliability scores improved gradually throughout the production program, and the bomb and rocket fuzes which were in production at the end of World War II gave scores as follows:

T–91E1 fuzes

92 per cent proper functions (average for 27 lots)
7 per cent random functions
1 per cent duds

The average height of function was 60 ft over a water target.

T–51 fuzes (M–166)

91 per cent proper functions (average on 230 lots)
9 per cent random functions
<1 per cent duds

The average height of function over the water target was 110 ft. The proper function range included heights up to 200 ft for bar-type fuzes.

T–2004 fuzes

94 per cent proper functions (average on 75 lots)
3 per cent random functions
3 per cent duds

The average height of the proper functions was 30 ft.

2. *Evaluation as a weapon.* A careful analysis of the T–5 fuze on the M–8 rocket as an antiaircraft weapon was made by the Applied Mathematics Panel. The study was based on the experimental performance of the fuze against a mock aircraft target, fragmentation data of the rocket, dispersion data on the rocket when fired from an airplane, and vulnerability of a twin-engine enemy aircraft (in particular, the JU–88) to fragmentation damage.

Conclusions of these studies were: (a) When fired from 1,000 yd directly astern with a standard deviation in firing error of about 50 ft (17 mils), a single round has 1 chance in 10 of preventing a twin-engine bomber from returning to base if it cannot return to base on 1 engine. (b) If return to base on 1 engine is possible, there is 1 chance in 16 that a single round will prevent its return. (c) If a delay of about 50 ft were incorporated in the fuze (to bring the vulnerable part of the target in a region of greater fragmentation density), the above probabilities would be increased to 1 in 4 and 1 in 6.

The probability of obtaining a crippling direct hit by an M–8 fired under the same conditions is about 1 in 100.

Limited tests and evaluations were made of the 5-in. AR and HVAR rockets equipped with T–30 fuzes as antiaircraft weapons. At the Naval Ordnance Test Station at Inyokern, California, some 70 rounds were fired from a fighter airplane at a radio-controlled plane in flight. At about 400-yd range, more than 55 per cent of the rounds functioned on the target. Eight high-explosive [HE] loaded rounds were fired, 4 of which functioned on the target, and 3 of the 4 destroyed the targets. Presumably, most of the rounds which did not function on the target were beyond the range of action of the fuzes.

The Army Air Forces carried out extensive evaluations of the effectiveness of air burst bombs against shielded targets using T–50 and T–51 fuzes on the M–81 (260-lb fragmentation) and M–64 (500-lb GP) bombs. Bombs were dropped on a large effect-field covered with target boards 2x6 in. in trenches 1 ft deep. The following conclusions are from the AAF report.

For equivalent airplane loads of properly functioning bombs dropped on 12-in. deep trench targets:

1. Air burst 260-lb M–81 fragmentation bombs and 500-lb M–64 general purpose bombs produce about 10 times as many casualties as contact burst 20-lb M–41 fragmentation bombs when trenches are 15 ft apart. (A casualty is defined as one or more hits per square foot, capable of perforating ¾ in. of plywood.)

2. Optimum height of burst for maximum casualty effectiveness is between 20 and 50 ft, with only slight variation through this range.

The British carried out similar appraisals using T–50 fuzes on M–64 bombs. There are several differences in details of the tests, particularly in the matter of evaluating the effectiveness of surface burst bombs. The British Ordnance Board made an appreciable allowance for the blast effect of both the contact-fuzed bombs and VT-fuzed bombs and arrived at a superiority factor of 4 to 1 for the latter against shielded or entrenched targets.

Studies by Division 2, NDRC, and by the British demonstrated that, when large blast bombs are air burst at about 50 to 100 ft above the ground, the area of demolition could be increased from 50 to 100 per cent. No full-scale tests were carried out to verify these conclusions, but it was established that the T–51 fuze could be used on both the 4,000-lb (M–56) American bomb and the 4,000-lb British bomb to give air bursts at the proper altitudes.

A number of evaluations were made to determine the effectiveness of air bursts for chemical bombs. In a carefully planned effect-field test using T–51 and T–82 fuzes on 500-lb light-case bombs, the British showed that the areas of contamination with a mustard-type gas were 4 to 5 times greater than when the bombs were used with contact fuzes. The increase was due to a more uniform distribution of the vesicant and avoidance of loss of material in craters.

The Chemical Warfare Service and the British cooperated in an extensive series of tests at Panama, in simulated jungle warfare. A T–51 fuze with reduced sensitivity effectively produced air bursts of chemical bombs below treetop canopies with efficient distribution of chemical materials.

Weapon evaluations of the type described above depend on the properties of both the fuze and the missile. In no cases were the missiles designed for proximity operation. Now that proximity fuzes have been established as practicable devices, certain missiles, such as fragmentation bombs for air burst use, should be redesigned to increase greatly their effectiveness as weapons.

Proximity fuzes for bombs and rockets saw very limited operational use, primarily because they were introduced into action very late in World War II. Altogether, approximately 20,000 fuzes, primarily bombs fuzes, were used in action by the Army and the Navy in the Pacific, ETO, and MTO. In the last few weeks of the Japanese War, approximately one-third of all the bomb fuzes used by carrier-based aircraft were proximity fuzes. The main targets were antiaircraft gun emplacements and airfields.

No thoroughgoing analysis of the operational effectiveness of the fuzes was possible, although the general reaction was very favorable. Since the fuzes were used in all theaters so late in World War II, the major uses were of a trial or introductory nature. In all cases, these trial uses were followed by urgent requests for more fuzes, which usually, and particularly in ETO and MTO, did not arrive until after World War II was over. Initial uses were all in 1945: in February in the Pacific, and in March in ETO and MTO. Reports concerning the effectiveness of the fuzes against gun emplacement targets usually stated that the antiaircraft fire was either stopped or greatly reduced after the air burst bombs exploded.

Although relatively little or no quantitative data as to the effectiveness of the fuzes were secured, their use was extensive enough to establish their practicability as Service items of ordnance equipment. Relatively little difficulty was experienced in the handling and use of the fuzes, and none of it was serious or unsurmountable. Hence, with the effectiveness of proximity fuzes well established by effect-field studies and their operational practicability established by combat use, proximity fuzes appear assured of a permanent and increasingly important position in modern ordnance.

1.3 BOMB, ROCKET, AND TORPEDO TOSSING

Toss bombing provides a method of improving the accuracy of bombing operations. The method can be used with bombs, rockets, and torpedoes, and, although applicable primarily to dive attacks, it is also effective in level, plane-to-plane attacks. In fact, the method can be employed wherever a collision course with the target can be flown for a short period prior to release of the missile. The object of the toss technique is to estimate and allow for the effect of gravity on the flight path of the missile. The latter is accomplished by releasing the missile from the aircraft with sufficient upward velocity above a line of sight to compensate for the gravity drop of the missile during its flight to the target. The release conditions are determined by an instrument which measures the time integral of the transverse acceleration of the aircraft during a pull-out above the line of sight and then releases the missile when this integral has reached the appropriate value as required by the time of flight of the missile. The time of flight is computed by the instrument prior to pull-out, while the aircraft is flying a collision course toward the target.

A typical toss-bombing attack is illustrated in Figure 7. The airplane enters a dive 2,000 to 5,000 ft above the point at which the projectile will be released and attains speed as rapidly as feasible during this dive. When the speed has reached a value sufficiently high for operation, and with the sight properly oriented on the target, the normal bomb release switch is closed by the pilot. Two or three seconds after the beginning of the timing run, a light near the sight comes on, indicating that the pilot may commence pulling out of the dive. When the angle through which the airplane has pulled up reaches the proper size, as determined automatically by the instrument, the release of the missile occurs. At this instant, the signal light goes out, indicating to the pilot that release has occurred and that thereafter he can employ any evasive action he desires.

If, after the timing run has begun, the pilot decides not to complete the maneuver, the action of the instrument can be stopped by merely opening the bomb release switch. This restores the electric circuits to a standby condition. The equipment can be

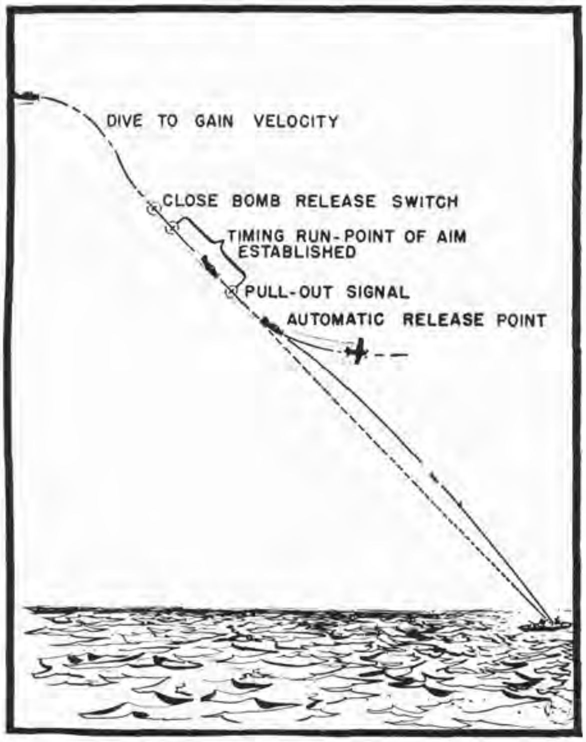


FIGURE 7. Diagram of typical toss-bombing maneuver.

made operative again, even in the same dive if remaining altitude and other conditions permit, by closing again the bomb release switch.

The development of the toss-bombing instrument was originally undertaken to provide a means of attacking bomber formations by using fighter airplanes carrying bombs. It was initially planned to use a head-on approach with high closing speeds and relatively small gravity drops of the bombs after release. The development was carried far enough to demonstrate that the technique offered excellent advantages as a defensive weapon against formations of bombers. However, in view of the rapidly increasing scale of the Allied air offensive at that time (late summer of 1943), the weapon was considered potentially more dangerous to Allied than to enemy operations. Work on the air-to-air portion of the project was therefore curtailed, and further development was directed toward applying the toss technique to dive bombing.

With the use of the toss technique, much less skill is required of the pilot. No visibility below the nose of the plane is needed, the range at which a given accuracy can be attained is much greater, the time during which the airplane flies a predetermined course is very short (usually about 3 seconds), and the pull-up preceding release constitutes an effective preliminary for evasive maneuvers should they be necessary.

The tossing technique is particularly useful in the case of low-velocity, fin-stabilized projectiles, such as bombs and the 11.75-in. aircraft rockets, since it removes the restriction on range which, in the case of the depressed sight technique, is imposed by limited visibility over the nose of the airplane.

In a series of evaluation tests in which slant ranges varied from 5,400 to 9,300 ft, 747 bombs were tossed. The pilots allowed for wind, using aerological data and the wind error indicated by the first bomb. In general, 5 bombs were dropped in succession. Fifty per cent of all the bombs were within a circle of 100-ft radius drawn about the target. When the pattern of impacts was projected onto a plane normal to the line of flight, 50 per cent of the impacts fell within a circle having a radius of 11.5 mils. As for the errors in range, 50 per cent of the impacts showed an error of less than 61 ft on the ground, or 5.8 mils normal to the line of dive. The corresponding deflection errors were 52 ft on the ground and 7.8 mils normal to the line of dive.

The impact pattern of 82 5.0-in. high-velocity aircraft rockets, launched in pairs with rocket-tossing equipment, showed that 50 per cent of the rockets lay within a circle of 9.6 mils radius normal to the line of dive. Fifty per cent of the rounds deviated from the main point of impact by less than 6.3 mils in range and 7.4 mils in deflection.

The toss equipment was used on a limited number of combat missions, in which it gave a circle of probable error [CPE] of 200 ft for all rounds released. Throwing out several rounds where misidentification of the target was established, the CPE drops to 150 ft.

All the data obtained by Division 4 in the rocket evaluation tests, and about half the data in the bomb evaluation tests, were obtained using experimental equipment designated as Bomb Director Mark 1, Model 0, AN/ASG-10XN. Modifications were made to the equipment to enable it to release rockets. The other half of the data in the bomb evaluation tests was obtained using production equipment for the release of bombs, designated as

Bomb Director Mark 1, Model 1, AN/ASG–10. Production equipment for the release of both bombs and rockets was designated as Bomb Director Mark 1, Model 2, AN/ASG–10A. The first production model was Service tested just before the end of World War II with satisfactory results. A later model, designated as Bomb Director Mark 2, AN/ASG–10B, had reached the experimental stage at the end of the war.

FIGURE 8. Components of Mark 1, Model 1, Bomb Director, less connecting cables.

The Mark 1, Model 0 equipment was manufactured as rapidly as possible in order to serve as a pilot model to work out production difficulties, as well as to get equipment into the hands of the Services for immediate use. Of this model, 500 sets were delivered to the Navy, which, in turn, transmitted 300 of them to the Army. Half of these 300 were sent to the European Theater, where some were used on 13 combat missions in P-47 airplanes.

The Mark 1, Model 1 equipment, shown in Figure 8, was developed on a contract basis during the production of the Model 0 units. Facilities were set up for production at an ultimate rate of 1,000 per month. This rate was not reached, because of the conclusion of World War II. Division 4 withdrew from the project during August of 1945, at which time the Navy Department took over sponsorship of further development and production.

1.4 MISCELLANEOUS PROJECTS

The work of Division 4 included survey investigations of various types of proximity fuzes other than the radio and photoelectric methods. Work on acoustic, electrostatic, and pressure-actuated devices (see Chapter 2) was carried far enough to establish that radio methods were superior. Work was also done on electrically adjusted time fuzes, but only as an interim project to the development of reliable radio fuzes.

Other projects of the Division included:

1. Development of rockets for use in testing proximity fuzes.

2. Initiation of development of target rockets for AA gunnery training, later taken over by Division 3.

3. Development of a new 81-mm trench mortar shell (in cooperation with the Engineering and Transitions Office) of improved ballistic properties, particularly when VT-fuzed.

4. Development of a machine for speeding up the computations involved in the degaussing of ships.

5. Initiation of a controlled-trajectory bomb (guided missile) project, later taken over and completed by Division 5. The controlled missiles were ultimately known as the Pelican and the Bat.[b]

6. Development of methods of treating cotton as a substitute for silk in powder bags.

The miscellaneous projects are summarized in Chapters 2 and 9.

---

[b] Reports of Division 5 should be consulted for further information on these important projects.

Chapter 2

PROXIMITY AND TIME FUZES

2.1 INTRODUCTION

2.1.1 Classification of Fuzes

A FUZE IS the mechanism which initiates the detonation of a missile. Fuzes may be classified in several ways, the two most common criteria being (1) according to the manner of triggering the explosive train, and (2) according to the position of the fuze with respect to the intended target. These may be expressed more briefly as classification with respect to design or use. The two methods of classification are, of course, closely related since the requirements of use will be reflected in the principles of design. Classification with respect to use may be grouped under three major headings, namely: (1) operation along the trajectory *before* reaching or while passing the target, (2) operation at the end of the trajectory *at* impact with the target, and (3) operation *after* impact with the target, usually after penetration into the target. In the two latter applications, either the deceleration of the missile at impact or the force of impact may be used to provide the energy necessary to initiate the fuze action. Such fuzes are variously referred to as contact, impact, inertia, or point-detonating. To secure function after contact with or penetration into a target, either a delayed action device may be initiated by the impact force, or a clock, started at the launching of the missile, may be used. The latter method is applicable only for relatively long delay times, or for cases when the accurate timing of the delay is unimportant. To secure function of the fuze before impact, the impact force is, of course, not available, and other methods of operation must be employed. An examination of these possible other methods is the object of this chapter.

There are two general methods by which operation of a fuze on a missile in flight [category (1) in the preceding paragraph] may be obtained. One is by timing, and the other is by proximity action with respect to the target. Both methods were investigated by Division 4. Detonation of a missile in flight is often called an air burst, a term which will be used frequently in this chapter.

Before discussing various types of time and proximity fuzes, it is desirable to review briefly the important applications of air bursts, since the intended use has an important bearing on the principles of design.

2.1.2 Advantages of Air Burst [a]

Targets for air burst missiles are primarily either airborne or surface targets. In the case of airborne targets, the objective of air burst action is to increase the effective size of the target so that it is not necessary to score a direct hit in order to damage or destroy the target. If, for example, a missile can be detonated in passing a target so as to damage it at distances up to 50 ft from its center, then the effective target area will be a circle of 50-ft radius. If the projected area of the target normal to the trajectory is 50 sq ft, then the target area will be increased over 150 times. Problems introduced by aiming errors and ammunition dispersion are thus greatly simplified. In the cases where such aiming and ammunition dispersion are large compared to the actual size of the target, the chances of producing damage are enormously increased.

The antiaircraft fuze problem, however, requires more than merely producing detonation within a specified distance (determined by the lethal range of the missile's fragments) of the target. The missile must be properly oriented with respect to the target. This requirement arises because the distribution of fragments from the exploded missile is not uniform in all directions. Usually the greatest number of fragments are projected approximately at right angles to the axis of the missile. Accordingly, the target should be in the direction of greatest fragmentation density at the instant of detonation if optimum effectiveness is to be obtained.

In the case of surface targets, the object of air burst action is to enhance the effectiveness of the lethal agents, which may be fragments, chemicals, or blast.

Air burst of a missile will allow the fragments to strike targets which would otherwise be protected or shielded from a contact burst, thus increasing the probability of damage. If, for example, the target

[a] These advantages are discussed in more detail in Division 4, Volume 1, Chapters 1 and 9.

is a man in a foxhole, it is a matter of simple geometry to show that because of the shielding effect of the walls of his trench, he will be protected from fragments from any surface burst except very close or direct hits. However, he will be exposed to fragments from any air burst visible from his foxhole and within lethal range. Thus an air burst increases the probability of damage, and, as in the antiaircraft case, increases the effective size of the target in the sense that missile trajectories do not have to intersect the target to damage it. A number of evaluations have been carried out concerning the optimum height for air burst against shielded targets.[13-19] These heights vary with a number of factors but generally fall within the range of 10 to 50 ft.

If it is desired to produce damage by blast, it has been found that air burst enhances the effect. Areas of demolition and minor damage as well are increased approximately 50 to 100 per cent by an air burst in the proper height range.[8] For the 4,000-lb M–56 bomb, the optimum height is usually between 40 and 70 ft.

If it is desired to cover an area with a chemical such as mustard gas or smoke, air burst of the missile containing the chemical increases the area of contamination. In this application, the chemical is distributed more uniformly over a wider area and without the loss of material in a crater. Optimum heights of function for this application have not been finally determined but appear to be of the order of 200 to 500 ft.[12]

2.1.3 Types of Air Burst Fuzes

The production of air bursts with time fuzes requires accurate knowledge of range. Against stationary ground targets at fairly short range, it is possible in artillery fire to obtain excellently placed air bursts with time fuzes. With longer ranges or against moving targets (involving a continuously varying range), the reliability of the air burst becomes less certain. Also, in bombing operations, satisfactory air burst cannot be obtained with time fuzes except from very low altitudes of release. Against aircraft targets, the problem with time fuzes is still more critical. Not only does the range vary continually, but the requirement for optimum effect (that detonation occur at the point on the trajectory where the greatest number of fragments will envelop the target) places severe demands on range determination and fuze accuracy. Modern radar-ranging techniques increased greatly the accuracy of range determinations and gave impetus to the development of more accurate time fuzes which could be quickly and automatically set at the time of firing. Work done by Division 4 on the development of such fuzes for antiaircraft rockets is discussed in Section 2.2.

Properly designed and reliable proximity fuzes greatly simplify fire control problems, and greatly increase the probability of damage. If the design of a proximity fuze is right, the fuze will detonate the missile automatically at the proper point of its trajectory to inflict maximum damage. No setting of the fuze on the basis of range estimates, before launching the missile, will be necessary. It is understandable, however, that the various applications mentioned above may require proximity fuzes of somewhat varying design.

In order that a fuze operate automatically on proximity to a target, it is necessary that it be sensitive to some form of energy which is either emitted by the target or emitted by some other source and reflected or absorbed by the target. Various forms of energy-sensitive devices which have been investigated or seriously considered by Division 4 are air pressure, acoustic, electrostatic, and electromagnetic, the latter including both the optical and radio-frequency portions of the spectrum. Magnetic devices were not investigated primarily because magnetic sensitivity varies as the inverse cube of distance and an apparatus with suitable magnetic sensitivity would probably have been too bulky for other than underwater missiles. Fuzes for the latter were not within the cognizance of Division 4. The relative merits of the above-mentioned types of energy-sensitive devices are discussed in Sections 2.3 to 2.7, inclusive.

Proximity fuzes, regardless of the form of energy to which they are sensitive, may be divided into two general classes: *active* and *passive*. An active-type fuze carries a source of energy which is radiated and then picked up after reflection from a target. A passive-type fuze is merely sensitive to energy incident on the fuze. In order for a passive-type fuze to indicate proximity to a target, either the target must be a source of energy or an auxiliary source must be available or provided to radiate the necessary controlling energy. Thus a passive-type fuze would be of simpler design and construction

[redacted]

than an active fuze. However, if an auxiliary source of energy has to be provided for the passive fuze, the overall system might well be more complicated operationally than for an active fuze.

The particular form of energy-sensitive device selected for fuze operation must be adaptable to the ballistic properties of the missile which is to be detonated. It was found that the principles of fuze operation and auxiliary equipment (power supply, safety features, etc.) depended closely on the properties of the missile. For this reason, fuze development was carried out under two general headings: (1) fuzes for spin-stabilized missiles, and (2) fuzes for fin-stabilized missiles, including bombs, rockets, and trench mortar shells. Division 4 was charged with responsibility for fuzes in the second category, and the following discussion is limited to that extent.[b]

2.2 RC TIME FUZES

2.2.1 Introduction

The production of air bursts with time fuzes, even with means available to obtain extremely accurate range data, may be considered as an interim method, prior to the development of an ideal proximity fuze. It was from this point of view that work, described in the next two sections, was done on time fuzes for two rockets, the British 3.25-in. antiaircraft rocket and the U. S. Army 4.5-in. M–8 rocket. The projects were terminated before completion for two reasons: (1) satisfactory radio proximity fuzes were developed, and (2) the rockets for which the fuzes were developed became obsolete for antiaircraft use.

A major advantage of a reliable time fuze over a nonideal proximity fuze is its independence of external stimuli after launching. Since a proximity fuze is by its very nature subject to external influence, it should be possible to introduce, in defense, factors which would cause the proximity fuze to malfunction or to operate on a false target. The production of such factors is called countermeasures, a subject which is beyond the scope of this volume.[c] However, the design of a fuze which would be highly resistant to countermeasures was a fundamental consideration in all fuzes developed by Division 4. Thus the immunity of a time fuze to countermeasures was important.

Another closely allied advantage of the time fuze was its relative lack of dependence on the properties of the missile after launching. This was particularly important in the case of rockets because of a phenomenon known as afterburning. In most rockets, the propellant does not burn completely during the main accelerating period but continues to burn sporadically for several seconds afterward. This afterburning may interfere with the proper operation of a radio proximity fuze.[d] Although the problem was ultimately resolved for the radio proximity fuzes (largely through redesign of the rockets), its initial serious nature gave priority to time fuze development for rockets for some time.

Electronic methods were selected over mechanical methods for the timing operations because of the easy and rapid adjustment of the time setting that the former afforded. The electronic circuits consisted essentially of a resistance-capacitance [RC] charging network and a thyratron. The latter fired an electric detonator to initiate the explosive action.

2.2.2 Fuze for 3.25-in. British UP Rocket

The development of an electric time fuze for use especially in high-altitude antiaircraft rockets (British 3.25-in. UP) was undertaken by the Research Laboratory of the General Electric Company under Contract OEMsr–99. A full summary of the development to termination is given in reference 7. The problem was to produce an accurate time fuze which could be set, by a simple voltage adjustment at the time of launching, to operate at times from 1 to 20 seconds. A simple setback arming switch was required which would keep the fuze safe for normal handling and operate to perform the necessary switching operations when subjected to a sustained acceleration of from 25 to $40g$.

The circuit elements, less switches, of the system developed are shown in Figure 1. The circuit contains a small impulse thyratron that discharges the anode capacitor through an electric detonator (not shown) when the grid potential ceases to be negative. Anode and grid capacitors are made equal. At time $t = 0$, an external voltage, which has maintained the anode at potential V_{a_0} and the grid at

[b] For information concerning work done on fuzes for spin-stabilized missiles, reference is made to the reports of Section T, OSRD.

[c] See reports of Division 15, NDRC.

[d] See Division 4, Volume 1.

potential $-V_{g_0}$ is disconnected from the circuit. The grid and anode potentials then drift toward their common asymptote. If the thyratron fires when V_g reaches zero potential, it can be shown that the

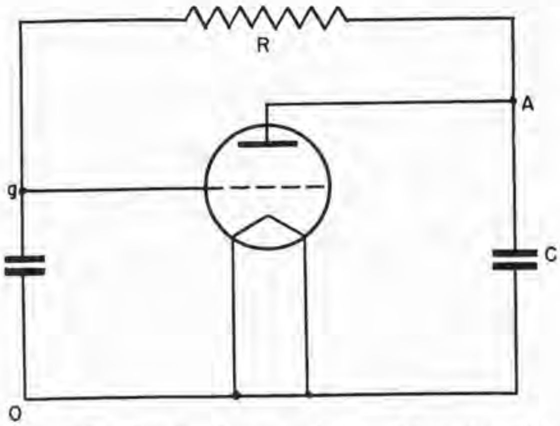


FIGURE 1. Circuit elements, less switches, for RC time fuze for 3.25-in. rocket.

firing time depends solely upon the ratio V_{a_0}/V_{g_0}. Thus the time of operation can be controlled by a simple potentiometer which varies the zero potential point of a total voltage applied across the points

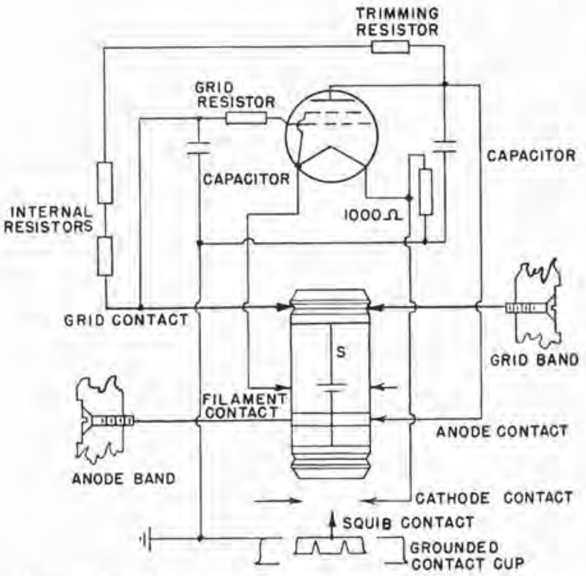


FIGURE 2. Complete circuit diagram for RC time fuze for 3.25-in. rocket.

a and g. This circuit was based on a British development known as the Benjamin circuit.

A circuit diagram of a completed fuze is shown in Figure 2. The element marked S moved down on setback to open and close the contacts indicated. This element also carried a 1.5-volt dry cell to heat the filament of the thyratron. The anode and grid bands were contacts on the exterior surface of the fuze to allow charging of the capacitor just prior to launching of the rocket. The capacitors were 1.1 microfarad and of the oil-impregnated paper type. The load resistors were 16-, 17-, and 18-megohm resistors (total 51 megohms) with low temperature coefficients. The thyratron was a special miniature type possessing excellent rugged characteristics.

Field tests on approximately 100 fuzes were conducted at the Aberdeen Proving Ground. Seventy-five per cent of the fuzes functioned with time variations as follows:

Expected Time (seconds)	Extreme Observed Deviation (seconds)
6.20	− 0.13 to − 0.05
15.28	− 1.11 to + 0.07
20.26	−11.2 to +13.5

The deviations on the short time were considered quite good. No satisfactory explanations were found for the unusual deviations at the 20-second setting. The load resistors were the least satisfactory part of the circuit, and it was realized that considerably improved reliability could be expected if better resistors were developed. There was also some indication that the method of removing the external capacitor-charging contact at firing interfered with the proper operation of the timing circuit.

2.2.3 Fuze for U. S. Army 4.5-in. M–8 Rocket

Development of a fuze for the 4.5-in. M–8 rocket was undertaken by the University of Florida under Contract OEMsr–949.[9] A starting point was the circuit described in Section 2.2.2 modified to allow the use of smaller resistors. In addition, greater stability was introduced in the circuit by connecting the grid to ground through a high-value resistor. A simplified circuit (less switches) is shown in Figure 3. The capacitors C_1 and C_2 are initially charged with the polarities shown with V_{10} larger than V_{20}. The voltages are maintained at their initial values by an external source until the instant of firing, at which time the external source is removed and the two-mesh RC network begins to discharge. When the grid-to-cathode voltage, originally negative, becomes approximately zero, the thyratron fires. The firing

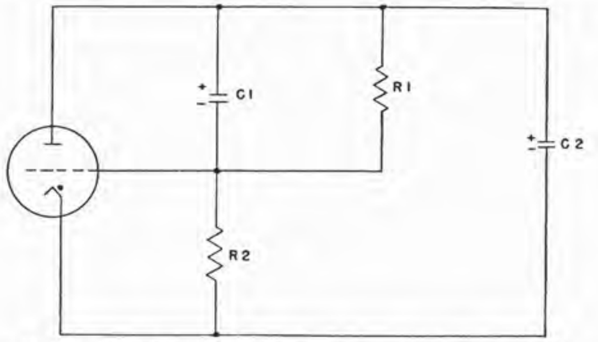


FIGURE 3. Circuit elements, less switches, for RC time fuze for 4.5-in. M-8 rocket.

time for optimum circuit conditions ($R_1 = R_2$ and $C_1 = C_2$) is shown, as a function of the ratio V_{20}/V_{10} in Figure 4. Accurate times were obtained by careful matching of the resistors and capacitors.

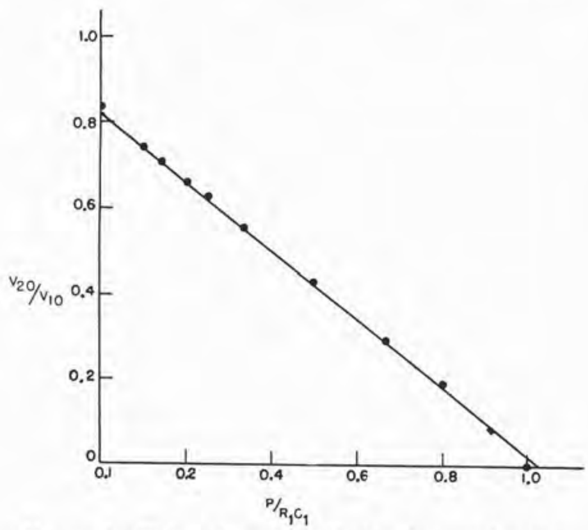


FIGURE 4. Firing times for RC time fuze as function of initial voltages.

In structure, the fuze followed the mechanical outline of the T-4 photoelectric [PE] fuze (see Figure 2, Chapter 3) and also the T-5 radio fuze.[e] These two proximity fuzes were also intended for use on the M-8 rocket. The setback switch for the time fuze was the same as used in the proximity fuzes.

A photograph of the fuze is shown in Figure 5. The charging rings may be seen at the tip of the ogive. Excellent results were obtained in laboratory tests; 50 per cent of the firing times at 20 seconds were within 0.2 second. In field tests, results were not so satisfactory because of difficulties with the external charging device. These difficulties did not appear insurmountable, but they had not been resolved when the project was terminated.

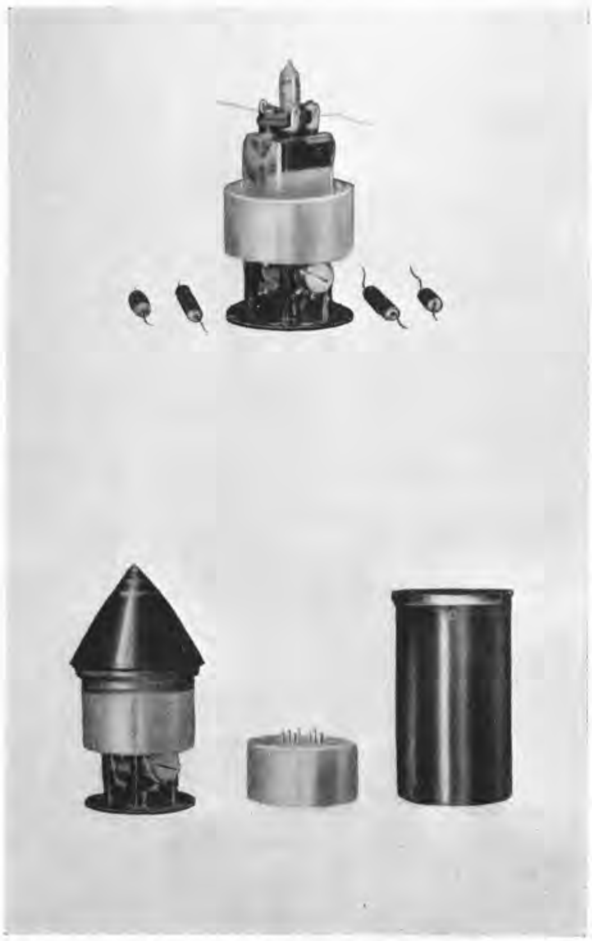


FIGURE 5. Views of RC time fuze for M-8 rocket. Top shows electronic components. Lower view shows, from left to right, assembled fuze with charging rings on ogive, switch, and fuze container. (University of Florida photograph.)

2.2.4 Capacitor Investigations

In connection with the development of RC time fuzes, and also for possible use in the filter circuits of generator-powered radio fuzes,[e] investigations were carried out on various dielectric materials to obtain a capacitor with improved space factor.[10,11] Both flexible and rigid designs were studied. A satisfactory design was obtained using a titanium mixture (No. 1242) as powder with a varnish binder as a flexible coating on tin foil. Two pieces of coated tin foil could then be rolled to make a tubular ca-

[e] See Division 4, Volume 1.

pacitor. Dielectric constants of 50 to 70 were obtained with power factors as low as 3 per cent.

2.3 PRESSURE FUZES

Air bursts can be produced on bombs by means of barometric or pressure-actuated devices. Such fuzes require for reliable operation precise knowledge of the ground pressure and release altitudes. Even so, the atmospheric pressure gradient is too small to obtain satisfactory operation in the 20- to 50-ft height range required for optimum fragmentation effect. Subject to the limitations mentioned, satisfactory operation of a barometric fuze might be expected at altitudes of 1,000 ft or higher.

No actual development was done by Division 4 on a strictly barometric fuze, but a combination barometric and time device (called a barotimer) was studied for use on bombs.[5] In this device, a clockwork time fuze is set continuously while in the airplane by a flexible sylphon, the extension of which varies with the atmospheric pressure at the altitude of flight. The sylphon sets the time fuze to the time that will be needed for the bomb and fuze to fall a desired distance. At the moment of release, an arming wire disconnects the fuze-setting sylphon from the clock and frees the clockwork. Thus, after the barotimer leaves the plane, the barometric timesetter has nothing further to do with the operation of the barotimer.

Although reliable laboratory operation to within 0.05 second was obtained, corresponding to drops from 4,000 to 12,000 ft, no field tests were conducted. It was concluded that, because of inherent variations in atmospheric pressure and possible lack of knowledge of the altitude (and pressure) at the target, the burst heights would be too variable. Accordingly, the project was terminated, and effort was diverted to other methods for obtaining air bursts.

Another type of pressure-actuated device for producing air burst was developed by the British. This fuze, called the No. 44 Pistol, contains a pressure-sensitive diaphragm which triggers the explosive action when subjected to a sudden increase in pressure. Air bursts of bombs are obtained by dropping several bombs fuzed with the No. 44 Pistol in a stick or train. The first bomb in the train explodes on impact or an inch or two before impact. The blast effect from the first bomb causes the other bombs to burst in the air. Usually about 50 per cent air burst operation is obtained in sticks of four bombs.

Evaluation of the method showed it to be about half as effective as radio proximity fuzes.[20]

2.4 ELECTROSTATIC FUZES

Considerable survey was done (under Section T, OSRD) concerning the possible use of electrostatic methods to produce air bursts, particularly for the antiaircraft application. The electrostatic method was very appealing, primarily because of its simplicity.

Operation of an electrostatic fuze depends on the electric charge on the target or on the missile or on both. The conclusions of the Section T investigations were that the charges on aircraft in flight and on the missile were too variable to insure reliable proximity operation.[2]

It is interesting to note that, in German attempts to develop a proximity fuze, their most advanced design was based on the electrostatic principle. Although results of German investigations concerning the charge on an airplane in flight were in reasonable agreement with American results, the Germans decided to accept the low sensitivity which such fuzes should have.

2.5 ACOUSTIC FUZES

The noise generated by aircraft in flight suggests the possibility of an acoustic type of passive proximity fuze for antiaircraft operation. It appeared that an extremely simple and reliable antiaircraft fuze could be designed and produced, provided that the noise generated by the missile itself did not introduce complications. Accordingly, extensive tests were conducted both by Division 4 (then Section E) [4] and Section T [3] to evaluate the noise generated by missiles in flight. Levels of sound intensity were measured both in wind tunnels and on missiles in flight.[6] The general conclusion was that the self-noise in the missile exceeded the noise level produced by the airplane at distances at which proximity operation was desired.

Various locations for a fuze in a bomb were investigated and it appeared that a nose location offered the best signal-to-noise ratio. Frequency-selective

[redacted]

devices were also studied, and it appeared that greatest discrimination between self-noise and target noise would be obtained in the region between 200 and 1,000 c.[4]

A number of schemes were proposed and some were studied for obtaining an adequate signal-to-noise ratio. One of the most promising involved the use of two microphones which would receive the target signal in equal phase and self-noise in random phase. Other systems involved working on rapid variations in noise gradient in selected frequency bands. Although it did not appear that an acoustic proximity fuze was impossible, it did seem that more effort would be required to obtain a satisfactory fuze of the acoustic type than for other types under consideration. Also, the velocity of sound appeared as a major limitation in the design and use of an acoustic fuze, particularly in high-speed missiles against high-speed aircraft.

The Germans had a large number of acoustic fuze projects, but none passed the development stage. In one of these (Kranich, an entirely mechanical device), the self-noise problem appeared to have been eliminated by a simple balancing scheme. This fuze operated on the doppler shift in noise frequency on passing the target.

2.6 OPTICAL FUZES

Designs for optical proximity fuzes can be considered for both passive or active operation. The simplest is, of course, the passive type, in which the fuze consists essentially of a light-detector. In the antiaircraft case, the target is a source of infrared radiation, which can be used to indicate proximity to a target. This principle, however, was not considered seriously until late in World War II, because earlier the available infrared detectors were too slow or too insensitive in response to be considered in fuzes. Another type of passive optical fuze uses the sun as a source of energy, the target as an interceptor or modulator of the energy, and a photoelectric cell as the sensitive detecting element within the fuze. Such a system offers a simple and straightforward basis for an antiaircraft fuze design, and the principle was exploited extensively by Division 4. The results of the investigations are presented in Chapters 3 to 8 of this volume.

A passive type of photoelectric fuze was developed by the British very early in World War II, and their work provided a starting point for American development. The results of the initial American survey on the possibilities of photoelectric fuzes are given in reference 1.

A major advantage of a photoelectric, or PE fuze, aside from its basic simplicity, is that the position of function with respect to an airborne target can be controlled with remarkable precision. The sensitivity zone of a PE fuze can be restricted to a narrow conical zone corresponding to the latitude of maximum fragmentation density of the missile.

There are, however, two major limitations to a simple passive photoelectric fuze: (1) since the sun is used as a source of energy, operational use is restricted to daytime, and (2) the sun is also a target in the sense that if the detector of the fuze "sees" the sun directly, malfunction of the fuze may occur. These two limitations were recognized in the beginning and led to termination of the work only after more difficult designs (radio) had proved practicable for proximity operation.

An infrared fuze would not be subject to the first limitation above but would be affected by the second. For this reason, infrared designs based on rapid, sensitive detectors developed by Division 16, NDRC, were abandoned after brief consideration. The practicability of available radio fuzes was also a major factor in the abandonment.

Several systems, which are described in the following chapters, were considered for eliminating the two major drawbacks of PE fuzes, but these were not fully exploited because of the success of the radio design.

It is of interest to note that the only proximity fuze used operationally by the enemy was an active-type photoelectric design, developed by the Japanese. The fuze, which was used on bombs, was about 10 times the size and weight of photoelectric fuzes developed by Division 4.

2.7 RADIO FUZES

In considering radio principles for proximity fuze operation, major consideration was given to active types. A passive fuze would require transmitting equipment as part of the fire control, which would increase the complexity of operational use. Although it was recognized that the radio method afforded ex-

[redacted]

cellent advantages in design flexibility to meet the requirements of various applications, there was some initial doubt as to the practicability of building a radio transmitting and receiving station into a fuze.[f] Here it is essential to state only that reliable designs were produced and that these designs represented solutions to most of the difficulties encountered in other types of proximity fuzes.

A major advantage of the radio method is that proximity operation can be obtained against any target which reflects radio waves. This means that a single basic principle can be used not only for the antiaircraft application but also for the variety of ground approach applications.

[f] The technical aspects of the design and production of radio proximity fuzes are given in Division 4, Volume 1.

[redacted]

Chapter 3

PHOTOELECTRIC FUZE DEVELOPMENT; INTRODUCTION AND SUMMARY

3.1 OBJECTIVES

PHOTOELECTRIC [PE] FUZES were developed for use on bombs and rockets against airborne targets. It was desired that the fuze detonate the missile at the point on the trajectory where the greatest number of fragments would be directed at the target. The sensitivity was to be such that detonation would occur for all rounds which passed the targets within lethal range of the missile's fragments. However, sensitivity design for extreme range of the fragments proved to be incompatible with reliable fuze performance, and an operating sensitivity between 50 and 100 ft was selected. Other desired requirements on which design considerations for the fuzes were based were:

1. The fuze should be as small and rugged as possible;
2. It should be safe for handling and operational use;
3. It should perform reliably under as wide as possible a range of Service conditions;
4. It should require a minimum of special equipment and training for its operational use;
5. It should be relatively immune to possible enemy countermeasures; and
6. It should have a self-destruction feature to operate, in case of a miss, after passing the target.

A number of compromises were made in requirement 3 in the interests of expediency. The principle of operation selected restricted the operation to daytime use. However, it was agreed that a good daytime fuze available early in World War II would be of more value than a 24-hour fuze available probably one or two years later. Another compromise was in the selection of a power supply for the fuze.

An ideal power supply would be required to operate over a very wide range of temperatures and have unlimited shelf life. Since no such power supply was available, it was considered desirable to design fuzes around dry batteries (which begin to fail at temperatures below 15 F and have limited shelf life) until better power supplies were developed.

Specific projects which were undertaken were: battery-powered fuzes for use on (1) large bombs,[1] (2) the British 3.25-in. UP rocket,[2] and (3) the 4.5-in. M–8 rocket,[3] and generator-powered fuzes for use on bombs [4] and rockets.[3]

Since the projects were carried out in view of recognized limitations in use, they were terminated as soon as more generally useful weapons (radio fuzes) were available and established as reliable.

3.2 PRINCIPLES OF OPERATION

The basic operating principles of all photoelectric fuzes developed by Division 4 are essentially the same. Operation can be explained simply by reference to Figure 1. The heart of the fuze is a photo-

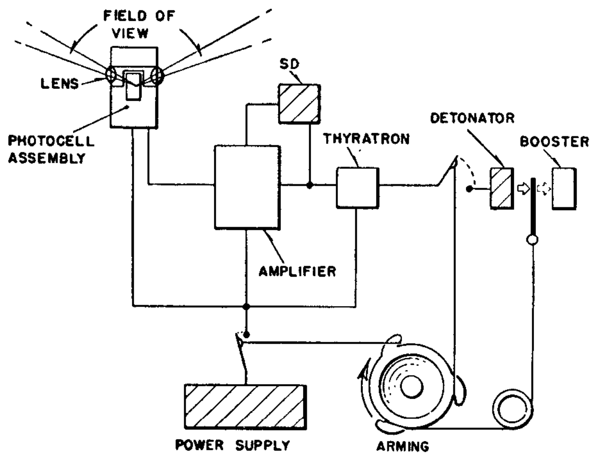


FIGURE 1. Block diagram illustrating operation of photoelectric proximity fuze.

electric cell (photocell) which is sensitive to light striking its active surface. The photocell is surrounded by a lens system which restricts the light which the photocell can see to a relatively narrow zone. This zone is called the field of view. The center of the field of view is conical in shape, and the field extends only a few degrees to either side of the center. Light outside of the field of view has no effect on the photocell. When a solid object, such as an airplane, enters the sensitive zone (field of view), it obstructs some light; consequently, the total light incident on the photocell is reduced. This causes a decrease in the output current of the photocell, which decrease is transmitted as a signal to the amplifier. The amplifier increases the amplitude of the signal to a level sufficient to fire the thyratron when a predetermined minimum percentage change in light level occurs. The amplifier also provides signal discrimination so that very slow or extremely rapid changes in light intensity are not transmitted as signals to the thyratron. This characteristic is described in more detail in Chapter 4. The triggering of the thyratron fires an electric detonator and the explosive action is initiated.

The preceding description applies only when the fuze is armed. Arming consists generally of three operations prior to which the fuze is insensitive: (1) application of power to the amplifier, photocell, and thyratron filament, usually at the time the missile is launched, (2) the connection of the electric detonator to the circuit and, generally at the same time, applying power to the thyratron plate, and (3) removal of a mechanical barrier between the detonator and booster, prior to which explosion of the detonator will not initiate the booster. The second and third operations occur at a predetermined time after launching. In the case of rocket fuzes, the arming system requires a sustained acceleration, such as is encountered when the rocket is fired, for its operation.

The arming characteristics of proximity fuzes are very important because the fuzes are sensitive to external influences and may be triggered any time after arming. The ability of a proximity fuze to withstand minor influencing factors and function only on the target is one measure of its reliability.

In the event that the fuze is not triggered by a target, usually because of passage too far away, a self-destruction [SD] circuit triggers the fuze at some predetermined time after launching.

Further details concerning the design, operation, and construction of PE fuzes are given in Chapters 4 and 5.

3.3 MODELS DEVELOPED

The first PE fuze developed was a tail-mounted bomb fuze intended for use in bombing formations of enemy aircraft. Only a few such fuzes were built and tested. Evaluation indicated that approximately 80 per cent of the fuzes which passed within about 100 ft of an airplane target could be expected to function properly on the target.[6] (See also Chapters 5 and 8.)[a]

The project was terminated because of lack of tactical interest in bombing aircraft with bombers.

The PE fuze on which the greatest effort was expended was the T–4 fuze for the M–8 rocket. A satisfactory design was achieved for this application, and approximately one-third of a million units were procured by the Army. This fuze is pictured in Figure 2. The fuze was designed to allow assembly with

FIGURE 2. T–4 photoelectric fuze, developed for use on M–8 rocket. From left to right are shown: assembled fuze ready for installation in rocket; MC–380 nose containing electronic control elements; BA–75 battery; and SW–230 switch. Nose and switch plug into opposite ends of battery.

a freshly tested battery in the field just prior to use. The battery and switch components of the fuze were identical with those used in the T–5 radio fuze. A full description of the electronic part of the fuze is given in Chapter 5. Reference is made to the radio volume[b] for a detailed discussion of the battery and switch.

In acceptance tests on over 4,000 production units, a reliability score of 90 per cent was obtained for the T–4 fuze. Of the remaining 10 per cent, approximately half were duds, and half were random functions, operating between the point of arming and the target. Further details concerning the evaluation of the fuze are given in Chapter 8.

None of the fuzes were used in combat because of a combination of reasons involving security, changes

[a] Most of the work on this project was done by Section T, OSRD, prior to its transfer to Division 4 (then Section E) in the summer of 1941.

[b] See Division 4, Volume 1.

in tactical requirements, and inadequacies of the M–8 rocket.[c]

Following the completion of development of the T–4 fuze, effort was directed toward the development of generator-powered fuzes for use in both bombs and rockets. As with the T–4 and T–5 fuzes, power supplies were designed and developed jointly for use on both radio and photoelectric fuzes. The successful development of a wind-driven electric generator as a power supply for fuzes removed the limitations of temperature and storage of the dry battery. Generator development is discussed briefly in Chapter 5 of this volume.[d] Photographs of generator-powered photoelectric fuzes for rockets and bombs are shown in Figures 3 and 4, respectively. The former was usually designated as RPEG (Rocket, PE, Generator), and the latter, as BPEG (Bomb, PE, Generator). The BPEG was also tentatively designated by the Ordnance Department as the T–52 fuze. Development of these two fuzes was terminated before completion because of the established reliability of radio fuzes.

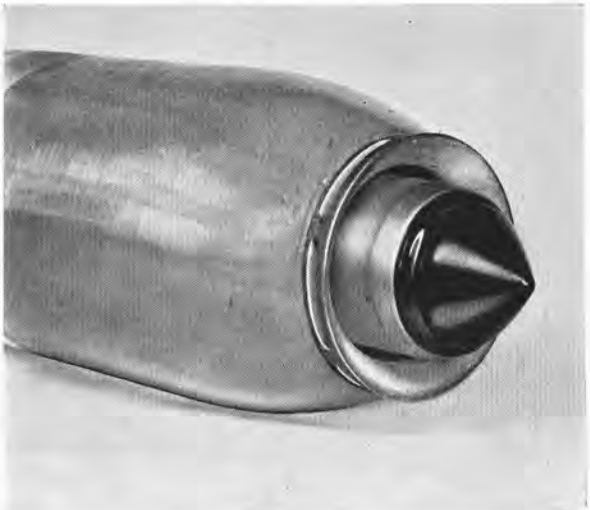


FIGURE 3. Generator-powered photoelectric fuze [RPEG] installed in M–8 rocket.

The production of reliable photoelectric fuzes involved extensive laboratory and field testing in order to evaluate performance under simulated conditions of operational use. Descriptions of these testing methods are presented in Chapters 6 and 7. A major problem encountered in designing electronic devices for use on high-speed missiles was microphonics induced by the vibration in flight, caused by turbulence of the airstream. Development and testing problems were appreciably concerned with making due allowance for possible vibration.

FIGURE 4. Generator-powered photoelectric bomb fuze [BPEG, or T–52]. (Bell Telephone Laboratories photograph.)

Although the following five chapters (4 to 8, inclusive) are concerned primarily with the T–4 fuze, some attention is given, particularly in Chapters 5 and 8, to methods considered for removing some of the limitations of the fuze. The presentation in these chapters may seem somewhat detailed for a project now classed as obsolete, but the presentation is considered pertinent for the following reasons.

1. The work described represents a summary of technical achievement which fulfilled or exceeded most of the initial expectations.

[c] See the Administrative History of Division 4, NDRC.

[d] For details of generator development, see Division 4, Volume 1.

2. Intelligence reports of foreign countries indicate that photoelectric devices were investigated extensively by other countries. Actually, the only proximity fuze used operationally by the enemy was a photoelectric fuze. Consequently, the development of countermeasures against possible future hostile fuzes can profit by having a fairly complete record of our own experience with photoelectric ordnance devices.

3. Some of the techniques and components developed may have other applications, either of peacetime or military nature. Actually, the photoelectric cell developed for the fuze has already found other applications.[e]

4. According to postwar plans of the Army Ordnance Department, optical fuze methods will be reinvestigated to determine ways and means of removing limitations or developing other applications. Consequently, this record should be of value as a starting point in such a survey.

[e] See Division 4, Volume 2, Chapter 8.

[redacted]

Chapter 4

BASIC PRINCIPLES AND DESIGN OF PE FUZES[a]

4.1 INTRODUCTION

THIS CHAPTER deals largely with those aspects of photoelectric [PE] fuze design which involve the interaction of the fuze with its target. Other general principles of the fuze design, such as mechanical problems of stability and ruggedness and electric power supply problems, are essentially the same as for the radio fuzes.[b]

PE fuzes were designed primarily for use against airborne targets. An ideal proximity fuze for this application would have the following characteristics.

1. It would detonate all projectiles which pass close enough to the target to cause appreciable damage.

2. The detonation would occur at the point on the trajectory of the missile where the explosion would inflict the greatest damage.

The PE fuze can be designed to meet both requirements under normal daylight conditions and some restriction on trajectory orientation with respect to the sun. The fuze is essentially a simple photoelectric triggering device. The proper burst point is obtained by restricting the light on the photocell to the direction which coincides with the maximum density of fragmentation.

Attainment of the above ideal operating characteristics may be considered to be the basic design problem of the fuze. The first involves the sensitivity requirements and the second the "look-forward angle."

Sensitivity is expressed either as the maximum distance of passage from a specified target at which the fuze operates (radius of action), or as the minimum percentage light change (threshold) on which the fuze operates. The main design problems are met in analysis of sensitivity requirements and design of circuits most suited to meet them. Proper design involves study of the interrelation of lighting conditions, target characteristics, photocell and amplifier properties, and other factors. The sensitivity characteristics of the fuze are governed by the following considerations.

1. There is an optimum design sensitivity which will give maximum fuze effectiveness. If the fuze were too sensitive, the increased percentage of fuzes which would detonate on passing the target would be outweighed by a decrease of fuze reliability.

2. The fuze must have approximately the same sensitivity over a wide range of light levels. This requires design of a circuit to convert the linear response of the photocell (proportional to the magnitude of the light change) to a logarithmic response (proportional to the percentage change in light).

3. The fuze must operate on an abrupt change of light. The circuit must be designed to be most sensitive to light changes at rates obtained when approaching or passing targets and less sensitive to extraneous signals from clouds or the ground.

4.2 DESIGN PRINCIPLES

4.2.1 Look-Forward Angle

The field of view of the photocell must have radial symmetry with respect to the axis of the fuze in order that the fuze may see the target at any aspect of passage.

The center of the field of view should be a cone corresponding to the direction of most intense fragmentation of the projectile. The look-forward angle is defined as the angle between the normal to the projectile axis and the center of the field of view (Figure 1). Look-forward angles on various models ranged from about 0 to 25 degrees. The look-forward angle is selected on the assumption that the center of the field of view is in the direction of maximum fragmentation of the projectile.

In considering the relation between the target signal and the time of detonation, experiments have shown that delays in the detonator and explosive train are negligible.[c] The time lag in the explosive train is of the order of 0.001 sec, which represents not more than 2 ft of travel of projectiles of the type for which PE fuzes were designed.

The direction of maximum fragmentation, i.e., the

[a] This chapter was written by Alex Orden of the Ordnance Development Division of the National Bureau of Standards and by Corporal R. F. Morrison of the VT detachment of the Army Ordnance Department.

[b] See Division 4, Volume 1.

[c] See Division 4, Volume 1, Chapter 3.

desired look-forward angle, can be determined for any proposed tactical application by vector addition of the velocity of the fuze relative to the target and the mean velocity of fragments from a projectile

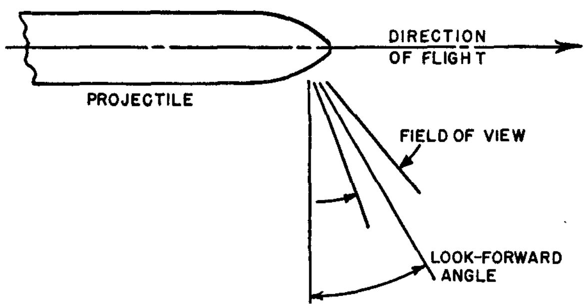


FIGURE 1. Field of view and look-forward angle.

exploded at rest. It is usually adequate to assume that the mean direction of fragmentation from a stationary explosion is normal to the axis of the projectile. Therefore, the look-forward angle should be

$$\theta = \arctan \frac{V_r}{V_f},$$

where

V_r = velocity of fuze relative to target and
V_f = mean stationary fragmentation velocity.

A typical example is: velocity of fuze relative to target in plane-to-plane pursuit firing with rockets is 1,000 ft per sec; mean velocity of fragments from stationary explosion is 3,000 ft per sec; therefore, the required look-forward angle is $\tan^{-1}$ (1,000/3,000) = 18.5 degrees.

The possibility of other tactical applications must be considered, and it may be desirable to select a compromise value for the look-forward angle. In the above example, a typical velocity of fuze relative to target for head-on plane-to-plane firing would be 1,600 ft per sec, which would require a look-forward angle of 28 degrees. Considering the size of targets and the angular spread in the fragment distribution, the look-forward angle may not be critical, a value selected for one tactical application being fairly effective in other applications. The spread in angular distribution of fragments from a projectile in motion is considerably greater than that for a stationary explosion, since the range of velocities of the fragments combined vectorially with projectile velocity spreads the angular coverage. For example, consider fragments concentrated in the direction normal to the projectile axis in a stationary explosion with a range of velocities of 2,000 to 6,000 ft per sec. When combined with a vehicle velocity of 1,000 ft per sec, the fragment spray would spread into a zone 9.5 to 26.5 degrees forward from the normal.

When reliable data on stationary fragmentation velocity distribution are available, it is desirable to use the true direction of maximum fragment density rather than assume that it is normal to the projectile axis.[9,1d] At the time of development of the T-4 fuze and earlier photoelectric fuzes, the data were rather meager. In particular, the M-8 rocket, for which the T-5 fuze was intended, was developed concurrently with the fuze. On the basis of predicted performance, a look-forward angle of 22.5 degrees was selected. It was subsequently shown [8,9] that a look-forward angle of about 0 to 5 degrees would have been better.[d]

4.2.2 Field of View

For design analysis the field of view (Figure 1) is represented by a lens transmission curve as shown in Figure 2. The angle between the 50 per cent

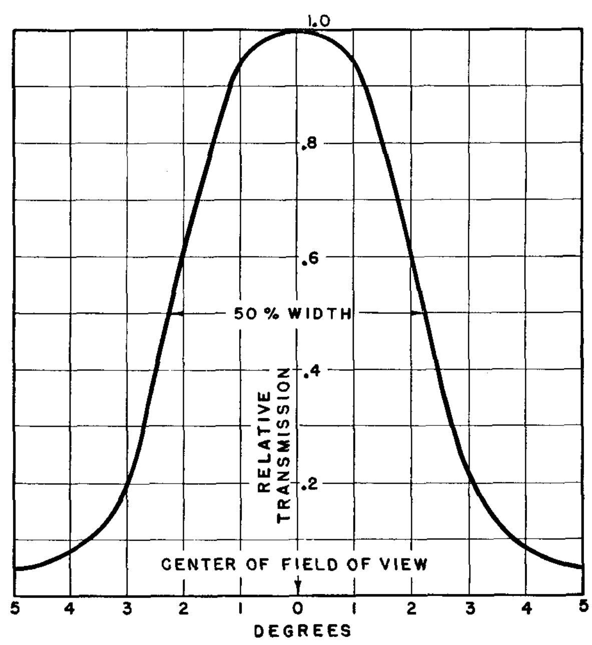


FIGURE 2. Lens transmission curve.

transmission points is frequently used as the parameter defining the field of view. This angle represents the width of an equivalent rectangular transmission

[d] See Division 4, Volume 1, Chapter 1.

[redacted]

curve, which would transmit approximately equal light flux.

The width of the transmission curve is controlled by the width of the slit between the lens and the photocell. The sharpness of cutoff is limited by lens aberrations.

The width and the cutoff slope of the transmission curve have considerable bearing on target pulse shapes, radius of action, susceptibility of the fuze to sunfiring, and response to stray optical disturbances. The shape of the lens transmission curve has been used in calculations in which the response of a fuze to a specified target was determined by analytical means.[6] However, no studies have been made to determine optimum lens transmission characteristics. Designs have been based on the following general considerations.

1. The width of the field of view should be equal to or less than the smallest angle subtended at the fuze by targets on which the fuze is expected to operate, i.e., the angle subtended by typical targets at a distance equal to the desired radius of action. With this design the target signal falls off inversely as the first power of the distance within the radius of action. At greater distances of passage, the target signal falls off inversely as the square of the distance, and the target signal rapidly becomes less effective.

2. A narrow field of view and a sharp cutoff appear to offer the simplest approach to reducing sunfiring and firing on extraneous light signals to a minimum for fuzes of standard design, i.e., not including the various experimental designs intended to eliminate sunfiring. The narrower the field of view, the less likely that the fuze will see the sun.

The ability of the fuze to discriminate between true targets and extraneous slower light changes depends on the selectivity of the amplifier for abrupt signals. Since the slope of the lens transmission curve affects the light signal from both true targets and extraneous light changes in the same sense, the slope of the transmission curve may not be critical, provided the lens and amplifier characteristics are properly matched.

3. Too narrow a field of view would result in loss of sensitivity at low light levels.

4.2.3 Radius of Action

The radius of action [ROA] of a given fuze model depends on target characteristics, lighting conditions, aspect at which the fuze sees the target, and velocity of the fuze relative to the target. For development and analysis purposes, it is desirable to establish standard field test conditions and a standard target. The radius of action under these conditions serves as a measure of fuze sensitivity and may be referred to as *ROA sensitivity*. Similarly, the minimum light change on which fuzes operate under specified laboratory test conditions provides a standardized measure of sensitivity, which is called the *threshold sensitivity*. The relation between ROA sensitivity and threshold sensitivity depends on the relative response of the particular fuze model to light pulses from targets.[6]

For analytical purposes, the radius of action is generally considered to define a zone within which all fuzes function and outside of which none function.

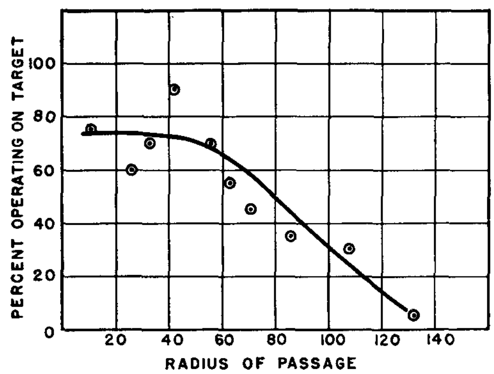


FIGURE 3. Per cent of fuzes operating on target versus radius of passage. (T–4 fuzes on 3¼-in. practice rockets fired against 12-ft diameter black balloon target.)

Statistical variation encountered in practice is shown in Figure 3. The distribution curve of per cent proper function is based on the firing of approximately 200 rounds of pilot production T–4 fuzes against a 12-ft diameter black balloon at Fort Fisher Proving Ground. (See Chapter 7.) The results indicate that the radius of action on individual rounds varied from 50 to 125 ft. The spread may be attributed in part to variation of internal fuze characteristics and in part to day-to-day variation of firing conditions, such as cloud conditions and target elevation.

In principle, there is an optimum ROA for which the fuze should be designed in order to make it most effective for a given application. The optimum value could be determined in advance as a basis for production design if experimental data were ob-

[redacted]

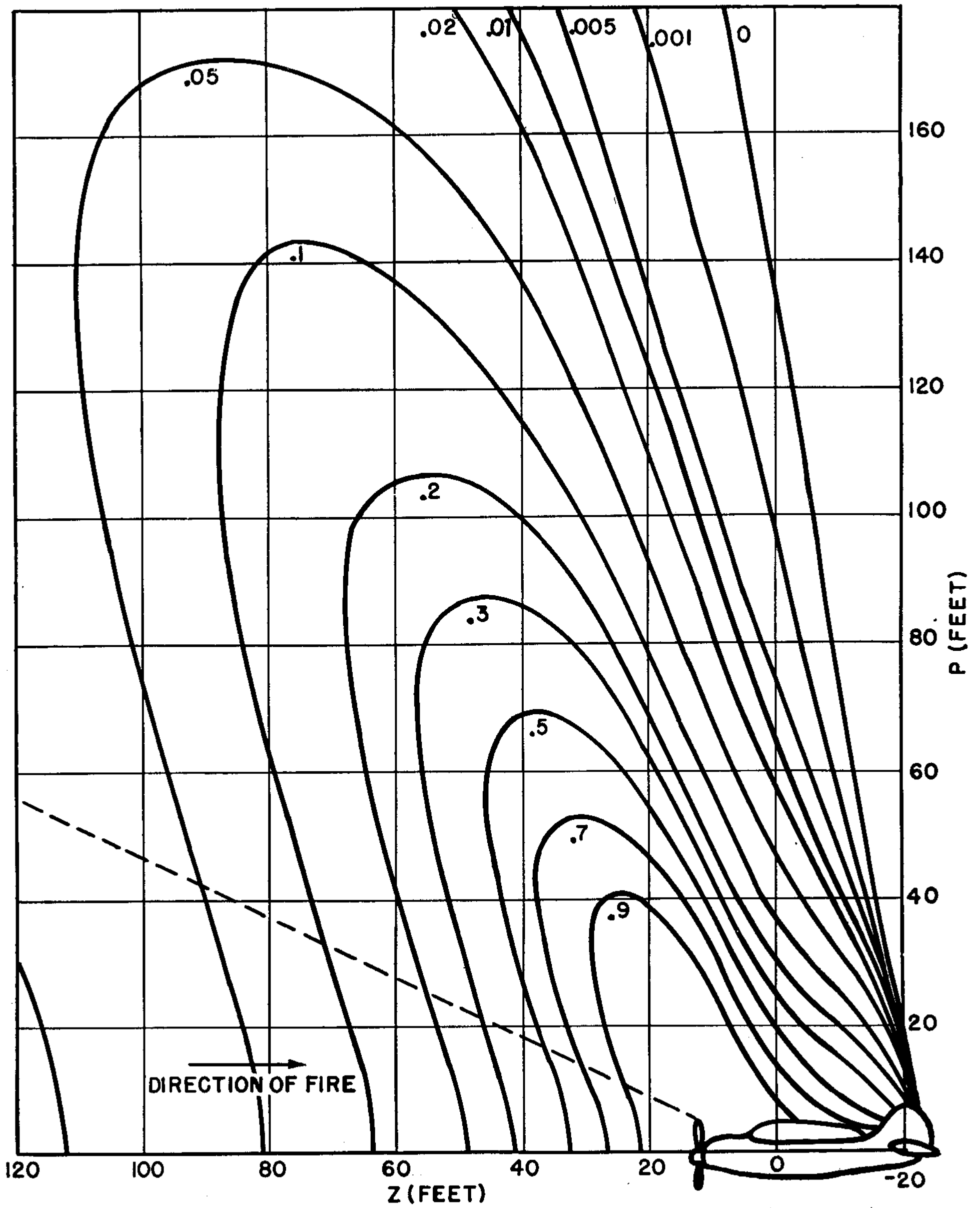


FIGURE 4. Probability of serious damage to SB2A airplane by 5-in. rocket shell. Figure on each curve is damage probability for points on that curve.

tained on: (1) damage probability as a function of distance of passage for projectile bursts [4,8]—as in Figure 4, and (2) fuze reliability as a function of ROA sensitivity—as in Figure 5. (Note that Figure 5 differs from Figure 3. Figure 3 shows statistical spread in sensitivity of fuzes of a particular design sensitivity; Figure 5 shows expected loss of fuze reliability due to increase of malfunctions with increase of design sensitivity.)

On the basis of data of the type shown in Figures 4 and 5 the determination of optimum design ROA is as follows: (1) The cumulative damage probability curve is obtained by integration of the conditional probabilities under the expected conditions of projectile dispersion and burst positions—see Figure 6. (2) The product of burst effectiveness (Figure 6) by reliability (Figure 5) then gives the overall probable damage as a function of design ROA—see Figure 7. This curve shows a maximum damage probability at the optimum design ROA.

[redacted]

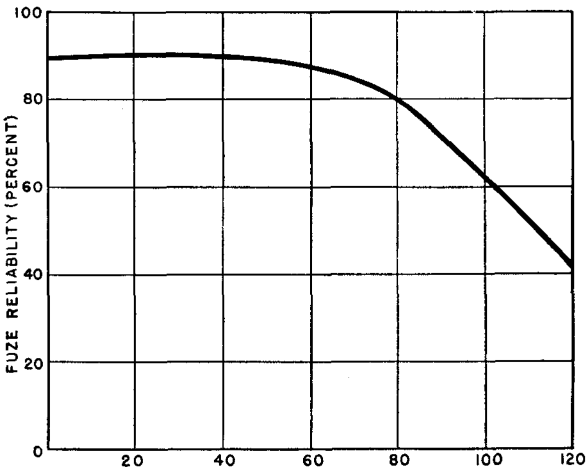


FIGURE 5. Fuze reliability versus fuze sensitivity (ROA). (Hypothetical curve used to illustrate design considerations given in text.)

The above procedure is applicable in principle but would require extensive advanced engineering and tactical information. It has been presented primarily in order to bring out basic considerations

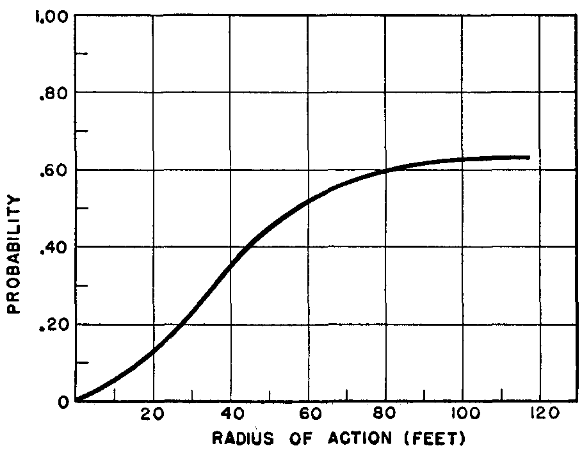


FIGURE 6. Cumulative probability that target airplane will be incapacitated by single rocket as function of fuze ROA. This curve is calculated on basis of Figure 4 under following assumptions: (1) rocket dispersion = 15 mils, (2) range = 1,000 yd, (3) fuzes function at look-forward angle of 30°, (4) for any ROA, all rounds which pass within ROA function against target and all rounds which pass outside ROA do not function.

with regard to the ROA. In the development of the T–4 the ROA requirement was based on the nominal lethal radius of the vehicle. The M–8 4.5-in. rocket was assumed to have a lethal radius of 60 ft. During the development of the fuze, it was field tested against a 12-ft diameter black balloon and required to produce a high proportion of target bursts on rounds passing within 60 ft of the target. Presumably, after the pilot design had demonstrated the required sensitivity, development of units of higher sensitivity would have been in order. In the case of the T–4 fuze, however, this was not done because of the urgency of getting a model into production. Moreover, an increase of sensitivity would have required a major design change, involving an increase in the number of stages of amplification.

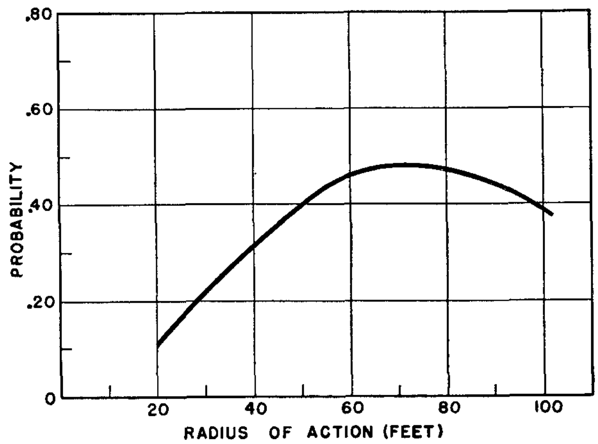


FIGURE 7. Overall probability of serious damage versus fuze sensitivity. This curve combines damage probability (Figure 6) with fuze reliability (Figure 5). It indicates that, under conditions of Figures 4, 5, and 6, a fuze designed to have ROA of 70 ft would have greatest effectiveness.

4.2.4 Target Analysis

DESCRIPTION OF LIGHT CONDITIONS

The magnitude of the light change due to a target depends on the brightness of the side of the target toward the fuze, relative to the background. When the fuze passes a target at any aspect at which the line of sight toward the target is above the horizon, the background of blue sky or of clouds is ordinarily brighter than the target, and the photocell receives a negative pulse. When the line of sight is below the horizon, the ground background may be lighter or darker than the target at low altitude, while with increasing altitude the background brightness increases because of light scattering by the atmosphere below. Thus the target pulse is generally negative, and the fuze circuit is designed accordingly.

As a first approximation to the characteristics of the target pulse, it may be said that the target obscures a fraction of the background light, and that, under given conditions of target shape, passage distance, etc., the fraction obscured is independent of the general light level. For this reason the fuze sensitivity is best measured in terms of per cent light change.

Discrimination of Target Signals from Background Light Changes

The principal limitations on fuze sensitivity are optical disturbances in the background and electrical disturbances within the fuze (noise and microphonics). The optical disturbances are mainly clouds, the horizon line, and nonuniform terrain. The percentage light change caused by these disturbances may be considerably greater than that which is due to a target. However, the rate of change of light due to a proper target is more rapid. Analysis of target characteristics permits design of an amplifier which is much more sensitive to pulses received from targets than to the slower pulses received from background variations.

The relative response to a near-by target and to background light changes depends also on the spectral response of the photocell. Scattering of light by the atmosphere increases as the wavelength decreases; therefore, the background generally appears more uniform to a photocell, whose response is largely in the short-wavelength region of the visible spectrum.

Light Measurement

The photometry involved in the fuze development, i.e., the measurement of light level and change of light, is most easily accomplished by using the fuze optical system and photocell as a light receiver and measuring the light in terms of microamperes of photocell current. Such data can be converted to light flux by calibration of the photocell in terms of microamperes per lumen.

Target Signal

The radius of action depends on many factors external to the fuze: shape, size, and reflection characteristics of the target, altitude, and atmospheric conditions. As a basis for analysis of the relation of any of these factors to fuze design, it is desirable to determine the curve of per cent light change vs time for fuzes passing targets under various sets of conditions.

Target pulse curves have been obtained by the following methods.

1. *Flyover tests.* The fuze was set on the ground, and the photocell current was recorded while a typical target airplane was flown over it. The time scale of the curve can readily be converted to correspond with any projectile velocity.
2. *Simulated target.* A small-scale model of a target was moved across a bright surface background to determine the pulse curve experimentally in the laboratory.
3. *Computation.* The shape of the target pulse was computed on the basis of the size and shape of the target and the transmission curve of the fuze lens. This method was used to obtain the pulse curves of the 12-ft target balloon, as shown in Figure 8.

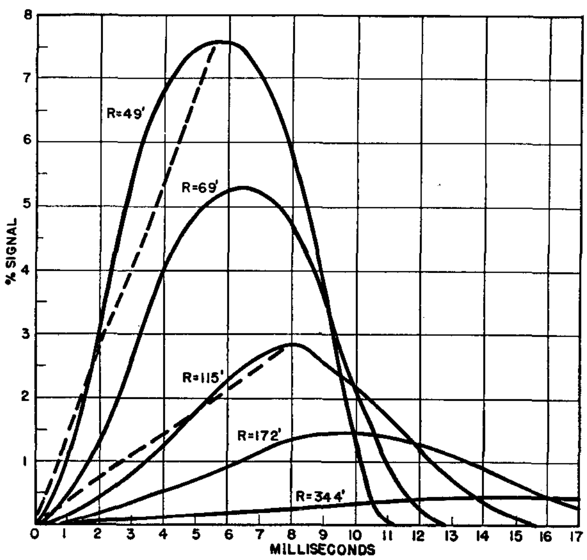


Figure 8. Target pulses from 12-ft diameter spherical target at various radii of passage (R). (Projectile velocity = 1,500 ft per second.)

Since it is not practical to consider the detailed relation of all external variables to fuze design, it is desirable to establish a simple standard target for development field testing and analysis. The pulse from this target should be representative of that expected from combat targets. A black balloon 12 ft in diameter was used for a large part of the T–4 development.

The radius of action against the standard target is established by field tests. This provides a basis for judging qualitatively whether the fuze sensitivity is adequate for expected combat targets and firing conditions.

The light threshold, or minimum per cent light change, on which the fuze will function depends on the shape of the target pulse. It is convenient to use a step pulse (instantaneous light change) for laboratory development experiments on fuze thresholds. (For production control testing, the threshold on a 60-c alternating light signal is most useful.)

THRESHOLD SENSITIVITY

The threshold sensitivity of a fuze is ordinarily given for a step pulse light signal. The threshold against actual targets varies with the duration and shape of the pulse. As an approximation, a target pulse may be considered as a linear decrease in light from the beginning of the light change to the instant of maximum obscuration (slant pulse). For an amplifier of the type used in the T–4, the threshold rises as the slant pulse time increases.

The relation between the threshold of a fuze on a step pulse and its threshold against a given target in the field may be computed by calculations

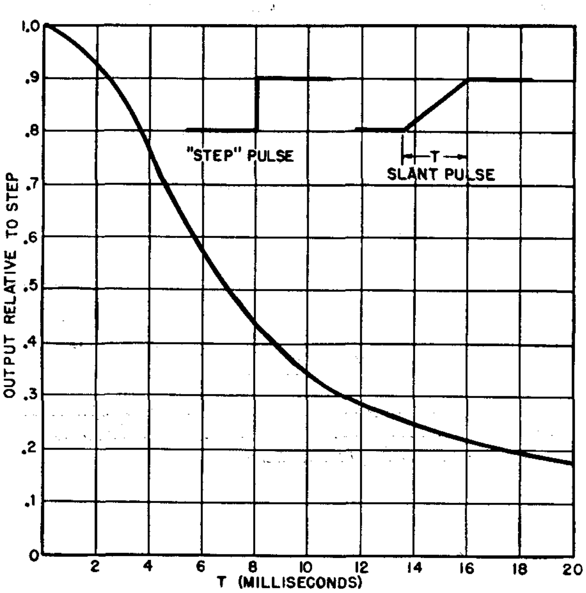


FIGURE 9. Amplifier output on slant pulse input signal of duration T relative to output on step pulse. Slant pulses serve as approximation to target obscuration signals.

using Heaviside operational calculus.[6] The relative output of a T–4 amplifier for slant pulses of varying duration is shown in Figure 9. (The threshold is inversely proportional to the relative amplifier output.) Figure 8, showing the target signal from a 12-ft balloon, gives slant pulse times of approximately 5 to 10 milliseconds for passage distances of 49 to 172 ft. For this range of pulse times, T–4 thresholds are 1.5 to 3 times greater than for a step pulse.

4.2.5 Light Level Variation

The light level, or total light flux on the photocell, varies with time of day, altitude, cloud and terrain conditions, and other factors. Since the change in light due to a target is approximately proportional to the light level, the radius of action against a given target can be kept approximately independent of light level by designing the fuze circuit to respond to the per cent change in light. There are many types of circuit whose response is sufficiently close to a percentage response for use in the photoelectric fuze.[1] The simplest of these is one using a nonlinear resistor (varistor or thyrite unit) as the photocell load resistor, as in the T–4 fuze.

Variation of light level with ambient conditions is shown in Figures 10, 11, and 12. Figure 10[3] shows the relative current of a photocell of the type used in the T–4 fuze over the course of a day. A rainstorm occurred at the time of the deep trough in the curve in the early afternoon. Figure 11 shows the variation of light level with time of day averaged over a week. Figure 12[5] shows the variation of light level with altitude, obtained with a photocell carried in an airplane. The relative responses with the photocell directed upward toward the horizon and downward toward ground and water are shown.

In order to cover the range of light levels generally encountered, the fuze should ideally have constant sensitivity to percentage changes in light over a range of light levels of at least 50 to 1, e.g., from about 0.5 microampere to 25 microamperes photocell current in a T–4 fuze. A design which meets this requirement can provide satisfactory operation from about 15 minutes after sunrise to 15 minutes before sunset. The rate of change of light level near sunrise and sunset is quite rapid; therefore, the low light level limit of adequate fuze sensitivity is not critical, since a change of fuze design, which extends the sensitivity to lower light levels, adds only a few minutes to the available operating time.

Circuits which have the required percentage response characteristic may be said to have a *logarith-*

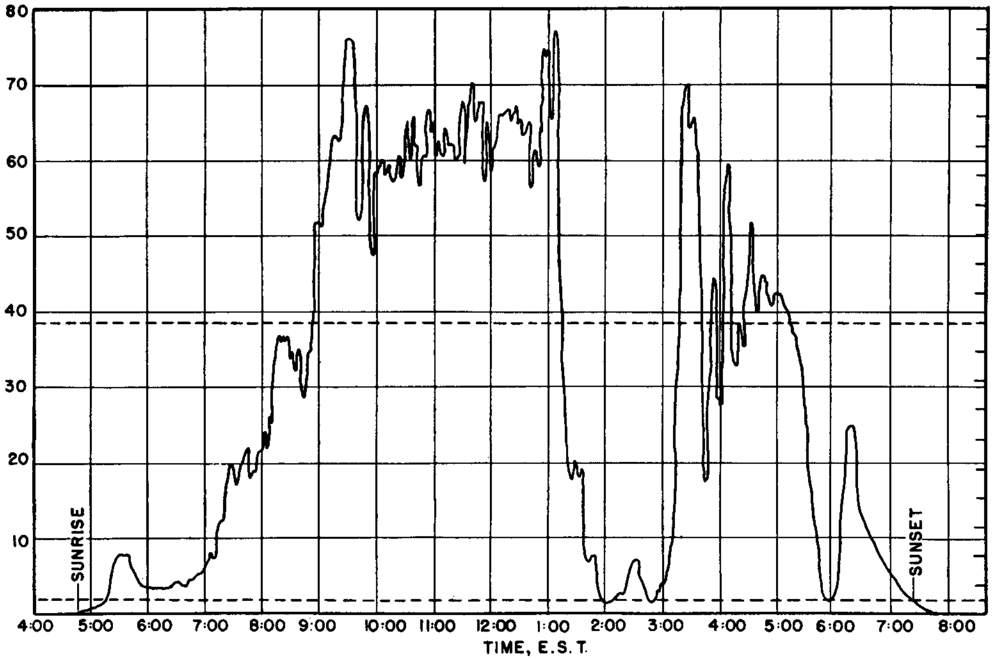


FIGURE 10. Relative light level seen by photocell of T-4 fuze during course of a day. (Rain between 2:00 and 3:00 p.m.)

mic response feature in the photocell circuit, or in the input element to the amplifier, or in the overall photocell and amplifier circuit. For example, if the photocell circuit is to be designed to provide a current change which is proportional to per cent light change we have

$$di \propto \frac{dL}{L},$$

and

$$i = K \log L,$$

where $\propto$ indicates "proportional to," i is photocell current, L is light flux, and K is a constant.

Thus the current in the photocell circuit must be proportional to the logarithm of the light level.

Alternatively, the photocell response may be linear, and the percentage response may be pro-

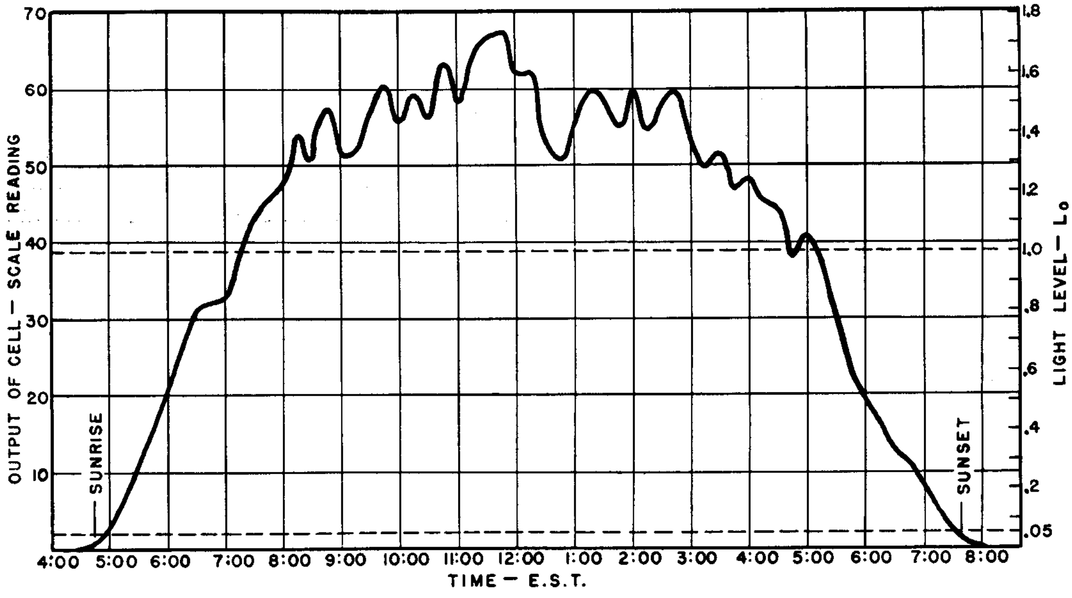


FIGURE 11. Variation of relative light level with time of day averaged over a week.

[redacted]

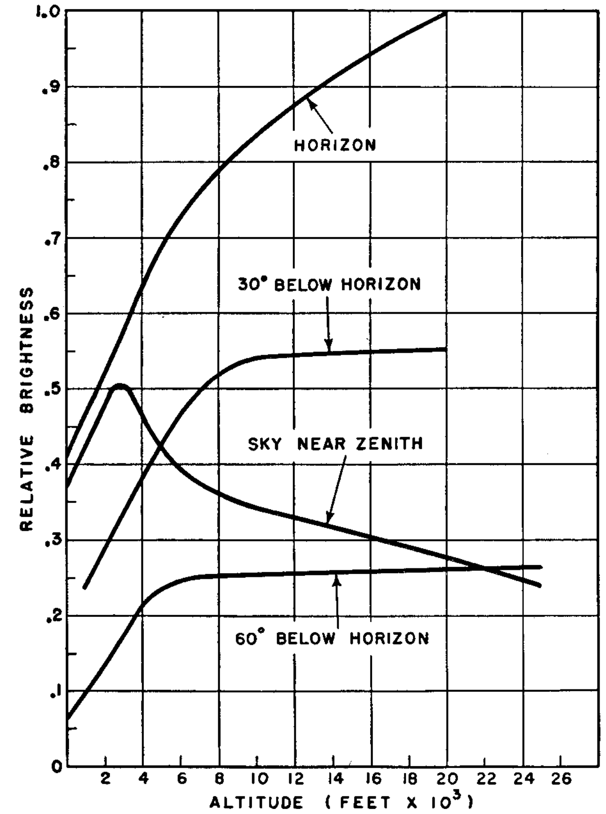


FIGURE 12. Variation of relative light level (seen by photocell) with altitude.

vided by the voltage input to the amplifier; i.e., the following relationships are required (v is amplifier input voltage).

$$
\begin{aligned}
i &\propto L, \\
di &\propto dL, \\
dv &\propto \frac{di}{i} \propto \frac{dL}{L}, \\
v &= K \log L.
\end{aligned}
$$

Thus in this case the voltage across the amplifier input is to be proportional to the logarithm of the light level.

4.3 BASIC DESIGN

The operation of the photoelectric fuze may be divided into three parts: arming; functioning on a target; and, in the absence of a target within firing range, self-destruction.

The arming mechanism delays the arming of the fuze so that the projectile is unable to explode until it has traveled a safe distance from the launching vehicle.

The self-destruction feature sets off the fuze after a given time, in case the projectile does not come within operating range of a target. This feature keeps live ammunition from falling on friendly territory and prevents capture of the fuze by the enemy when it is used over enemy territory. It is also useful for testing operation of the fuze in development work.

4.3.1 Mechanical Design

The fuze must be of small size and weight so that it does not take up a disproportionate share of the projectile. Since it is mounted at the front of the projectile, its shape must be such that it does not detract from the ballistic properties of the projectile.

The photocell should be mounted as far forward as possible so that the lens will support the least weight, and the amplifier is mounted next to it so as to keep the leads to the photocell as short as possible. The arming mechanism should be placed to the rear because it contains the electric detonator, leaving the battery between the amplifier and the switch.

For convenience in manufacture and testing, the T–4 fuze was made in the form of subassemblies which could be assembled just before use. These subassemblies were: photocell-amplifier unit, battery and thyratron-firing condenser unit, and switch-detonator unit. Testing immediately before use was especially desirable in the case of the dry cell battery, which suffers rapid deterioration in some climates.

The components and final assembly of the fuze must be rugged so as to withstand the acceleration to which the fuze is subjected. Vacuum tube elements must be so mounted that vibrations which might produce signals within the passband of the amplifier are of very small amplitude. Amplifier components are mounted on a bakelite plate and the amplifier cavity is filled with a potting compound such as ceresin wax having good electrical insulating properties. This holds the components rigidly in place. The wax serves the additional function of moistureproofing the unit.

Some means of delayed arming must be provided as a safety feature to prevent premature explosions. The switch of the T–4 fuze incorporated a number of safety measures: the plate and filament supply circuits were kept open before firing, while the detonator leads were shorted and a metal plate was kept between the detonator and the booster.

The switch was operated by the acceleration of the rocket and was so designed that it could not be set off by accidental jars due to dropping, etc. The acceleration closed the A and B circuits immediately upon firing. About 0.5 second later the arming was completed by connecting the detonator into the plate circuit of the thyratron and sliding the metal plate over to provide an opening through which the explosion of the detonator could reach the booster.

4.3.2 Optical Design

The optical system of the T–4 fuze was designed to see a ring of sky about 5 degrees wide and 20 to 25 degrees forward of the equatorial plane of the projectile. This width was about equal to the minimum angular width of the target at the lethal range

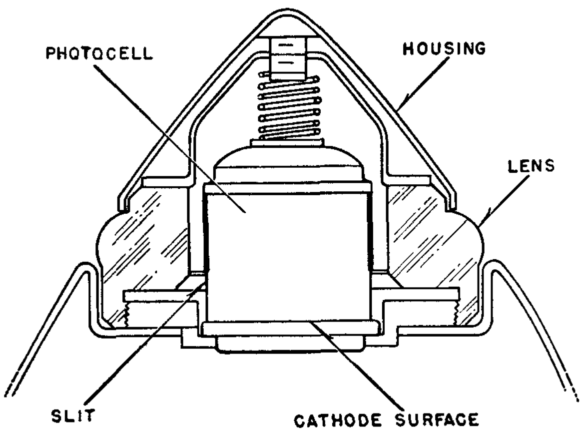


Figure 13. Optical system of T–4 fuze (simplified).

of the shell, and the direction was determined by the expected fragmentation cone of the M–8 rocket. The optical system consisted of a toroidal lens set in the outer case of the fuze and a ring slit surrounding a photocell at the axis of the fuze. (See Figure 13.)

The lenses were made of Lucite or Plexiglas and formed either by machining a plate of Lucite to the required shape or by molding the plastic and machining only the optical surfaces.

Since the smaller radius of curvature of the toroid was small compared with the larger radius, the focal properties of the toroid were approximately those of a cylindrical plano-convex lens. The image of a distant point of light was a line in the case of a cylindrical lens, and for the toroid it was roughly the arc of a circle of radius equal to the larger radius of the toroid.

To find the radius of curvature, it was convenient first to compute the focal length of a lens of unit radius and of the proper relative width and thickness for refractive index 1.49. The required radius of curvature was then the desired focal length divided by the focal length for unit radius. The lens was made as wide as possible without introducing serious aberrations. This width was approximately 1.2 times the radius of curvature. The optimum focal length of such a lens was less than that of a narrow lens. For a narrow lens of unit radius and of thickness equal to the radius, the unit focal length was 2.37 cm, whereas for the wide lens it was 2.20 cm.[1c]

The slit which was placed at the principal focus of the lens was made in a number of ways. One method was to bring the light to a focus at the surface of the lens block or the photocell wall. The lens surface or photocell wall was then painted black and the paint cut away to form the slit. An alternate method made use of opaque sleeves placed over opposite ends of the photocell and so spaced as to form a slit.

The position of the slit along the axis of the fuze controlled the look-forward angle of the fuze, and the slit width controlled the angular width of the ring of sky seen by the fuze.

The earlier models of the photoelectric fuze utilized photocells with conical cathodes, whereas the later models used photocells with flat cathodes. The flat cathode enabled light from the area seen by the fuze to spread evenly over the entire cathode surface. This smoothed out inequalities in the emission from various parts of the cathode and provided a more uniform response to light from various directions.[2]

4.3.3 Electrical Design

The electrical design of the PE fuze may be divided into four subcircuits which may be designated as (1) the input circuit, (2) amplifier, (3) firing circuit, and (4) self-destruction [SD] circuit.

Input Circuit

The input circuit design must involve a means of coupling the amplifier to the high-impedance photocell circuit as well as provide a logarithmic response so that the amplifier will respond to a certain percentage change of light intensity regardless of the general light level. These requirements can be met by use of various nonlinear impedances, such as vacuum tubes operating over the curved portion of their characteristic, or by resistive materials, such as thyrite, whose impedance depends upon current density.[1a]

Early models of the photoelectric fuze made use of a vacuum tube connected so that the photocell current flowed between the grid and cathode of the tube. With this arrangement, larger currents resulted in lower grid-cathode impedance and, hence, lower gain. This model used three stages of amplification.

In later models (T–4), use was made of thyrite resistors, whose impedance varies inversely with current density. The use of the thyrite resistor and adoption of the single-stage amplifier simplified the unit considerably. Some difficulty was experienced due to the high-impedance grid resistor (90 megohms) used with this amplifier. Development of photocells of higher sensitivity made it possible to reduce this to a lower value.

Amplifier

The type of amplifier to be used depends upon a number of factors. The frequency characteristic of the amplifier must be such that the frequencies predominantly present in the electric pulse generated in the photocell by the passage of the projectile past the target will be amplified, and no others.

Since the current in the photocell is proportional to the light falling upon it, the pulse shape will be determined by the rate at which light is cut off from the cell and will be different for different aspects of the target. A careful analysis shows that these differences are important only when close to the limit of sensitivity. In no case is the light cut off very abruptly. The shape of the later stages of the pulse is not of particular importance since the initial stages will nearly always fire the unit in actual use. There is a gradual diminution in the light as the target passes into the field of view. Therefore, as a first approximation, the time required for the change from full illumination to the illumination with the target in the field of view is taken to be one quarter period of the strongest frequency in the pulse.

Since the relative velocity as well as the separation of the missile and target may differ with each round, the frequency of the pulse will not be a constant. A shaped amplifier with maximum gain at 100 c and 50 per cent of maximum gain at 30 and 800 c proved satisfactory in the T–4 fuze. Variations in light level and noise, due to the low-frequency yaw of the projectile as well as high-frequency vacuum tube microphonics, were greatly reduced by this shaping.

The gain of the amplifier was sufficient to give

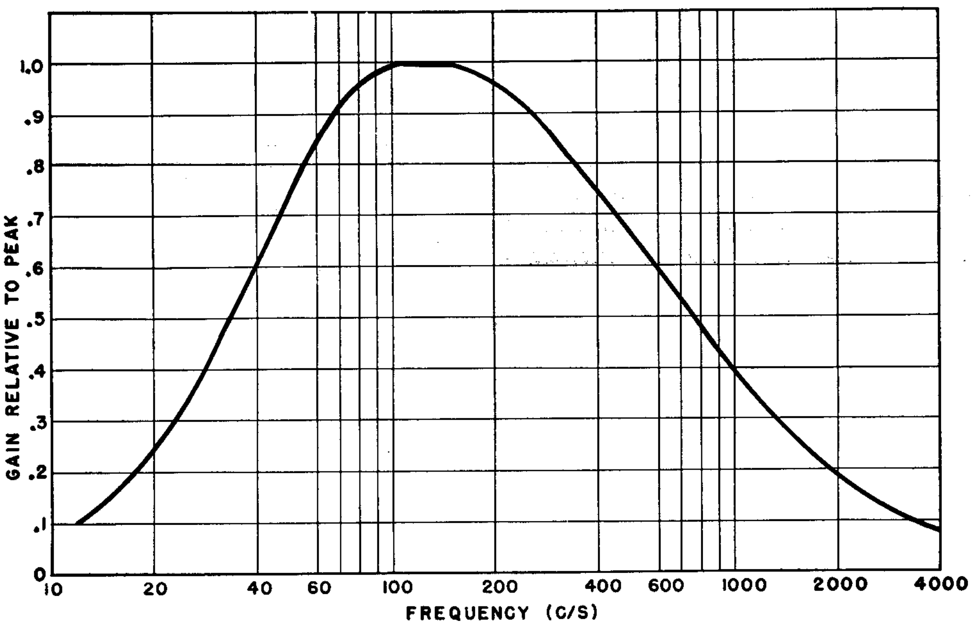


Figure 14. Gain-frequency curve of T–4 amplifier.

[redacted]

an output of about 4 volts for a 1 per cent light change in the photocell illumination. The photocell-varistor combination generally used in the T–4 fuze gave a voltage output of about 0.1 volt per 1 per cent change in light intensity, which indicated that a voltage gain in the amplifier of about 40 was necessary.

The gain vs frequency curve for the T–4 amplifier is shown in Figure 14, while the amplifier circuit diagram is shown in Figure 15. The condensers C_{sg}, C_p and C_c provide the low-frequency cutoff, while C_p determines the high-frequency cutoff.

The peak frequency gain of about 40 obtained with this amplifier was near the maximum that could be obtained in a single stage without the use of regenerative feedback.

Firing Circuit

The main elements of the firing circuit were the thyratron and the squib, or electric detonator. The thyratron was furnished with negative grid bias about 4 volts in excess of that necessary to prevent firing. The amplifier output was coupled to the thyratron grid through a condenser. An output pulse (from the amplifier) of greater magnitude than 4 volts would, therefore, cause the thyratron to fire. The detonator was connected in the plate circuit of the thyratron and carried the plate current of the thyratron, which, when triggered, was large enough to cause explosion of the squib.

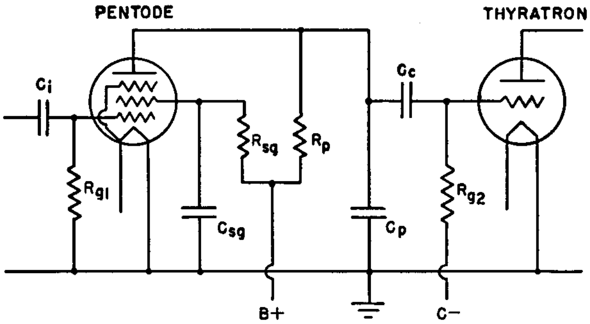


Figure 15. Circuit diagram of T–4 amplifier.

Self-Destruction

A self-destruction feature was incorporated in the fuze to prevent capture of duds by the enemy and to prevent damage to ground forces when used over friendly territory. A time of approximately 10 sec was required.

The self-destruction circuit of the T–4 fuze consisted of a condenser, which was slowly charged through a high resistance until it discharged through a neon lamp. The voltage drop across a resistor in series with the neon lamp was used to pulse either the amplifier or the thyratron.[e]

Difficulties due to inconsistent breakdown voltages of the neon lamps were eliminated by using lamps containing small amounts of radioactive material.

4.3.4 Power Supply

The power requirements of the T–4 photoelectric fuze were moderate, and, in fact, appreciably less than for the T–5 radio fuze. Batteries which had deteriorated so that they were below tolerance for the T–5 fuze could be used for T–4 fuzes.

The electronic circuits required a high-voltage plate supply, a filament supply, and a grid bias voltage.

A plate supply voltage of 138 volts was found sufficient to supply the photocell and amplifier as well as the thyratron. The steady current drain was small, less than 300 microamperes for the photocell and amplifier. A large current pulse, however, was required to fire the detonator. This requirement was met by using the discharge of a capacitor through the thyratron to fire the detonator.[e] A capacitor of 1.6 microfarads was built into the power supply for this purpose.

The tubes used required a filament supply voltage of 1.5 volts. The current drain was less than 200 milliamperes for the T–4 fuze.

A grid bias voltage of at least 6 volts was required for the thyratron, and a bias of 1 or 2 volts for the amplifier, depending upon the type of pentode used.

[e] See Division 4, Volume 1, Chapter 3.

Chapter 5

DESCRIPTION OF PHOTOELECTRIC FUZE TYPES[a]

5.1 INTRODUCTION

All photoelectric [PE] fuzes developed by Division 4 operated on the same basic principle and followed the same general electrical design. The method of operation and general procedure for design have been described in Chapters 3 and 4. The major differences in the various models were in mechanical layout and assembly, and in the method of arming, as required by the properties of the missiles for which they were intended. There were also differences in the method of obtaining the so-called logarithm characteristic and in the properties of the electrical components. The logarithm characteristic, as described in Chapter 4, insured uniform sensitivity at various levels of light intensity.

Models were developed for four different sets of military requirements. However, all these were for antiaircraft use. These models were, in order of development:

1. Model C, a tail-mounted bomb fuze for air-to-air bombing;
2. Model BR, or Mark 1 (Ordnance designation), a nose-mounted rocket fuze for the 3.25-in. British antiaircraft rocket;
3. T–4, a nose-mounted fuze for the 4.5-in. M–8 rocket intended for air-to-air operation;
4. BPEG, or T–52 (Ordnance designation), a nose-mounted bomb fuze for air-to-air bombing, primarily in connection with toss bombing.[b]

There were also several interim or developmental models [1,3,104] preceding each of the four listed above. Of the four models listed, only the T–4 fuze was produced in quantity. The Army procured approximately a third of a million T–4 fuzes, with four manufacturers participating in the production program.

The Bomb, PE, Generator fuze [BPEG] was practically ready for production release at the time work on photoelectric fuzes was terminated.

The Model C and BR fuzes are described in Section 5.2, the T–4 in Section 5.3, and the BPEG fuze in Section 5.4. Also described in Section 5.4 are several experimental models developed to improve the usefulness of the photoelectric method in general and the T–4 fuze in particular. The important properties of the photocells developed for the PE fuzes are described in Section 5.5.

Methods and results of testing and evaluating the fuzes are covered in Chapters 6, 7, and 8.

5.2 EARLY PE FUZES

5.2.1 Model C Fuze[1,3,104]

General. A photograph of the Model C fuze is shown in Figure 1 and a circuit diagram of the electronic assembly in Figure 2. The fuze was assembled in a steel tube 3.25 in. in diameter and 12 in. long. The tube was clamped in an adapter which, in turn, was screwed to the rear of the bomb, replacing the fin-locking nut. These fuzes were tested only on inert-loaded bombs, using spotting charges, and for this purpose the electric detonator was attached exterior to the fuze. The project was terminated prior to the development of a high-explosive detonating system. A detailed description of the Model C fuze may be found in reference 1.

Optical System. A toroidal lens [1] made of Lucite provided a conical field of view centered 80 degrees back from the forward axis of the bomb. (Look-forward angle of 10 degrees, see Figure 1, Chapter 4.) The width of the field of view (defined in Chapter 4) was 2 degrees. The photocell was a vacuum-type, blue-sensitive cell.

Amplifier. The input stage [1,3] of a three-stage amplifier provided a variable load resistance for this photocell. When connected as shown in Figure 2, the input impedance of the first tube decreased as the photocell current increased. This characteristic insured that, at various light levels, a given percentage change in light level incident on the photocell would give a signal of reasonably constant magnitude. The resistors and capacitors of the amplifier were chosen to give a peak gain at about 20 c. The overall sensitivity was such that a decrease of about 0.5 per cent in the light incident on the photocell would trigger the thyratron. Actually, the sensitivity varied from

[a] This chapter was written by Charles Ravitsky, T. M. Marion, W. E. Armstrong, and J. G. Reid, Jr., all of the Ordnance Development Division of the National Bureau of Standards.

[b] See Division 4, Volume 2.

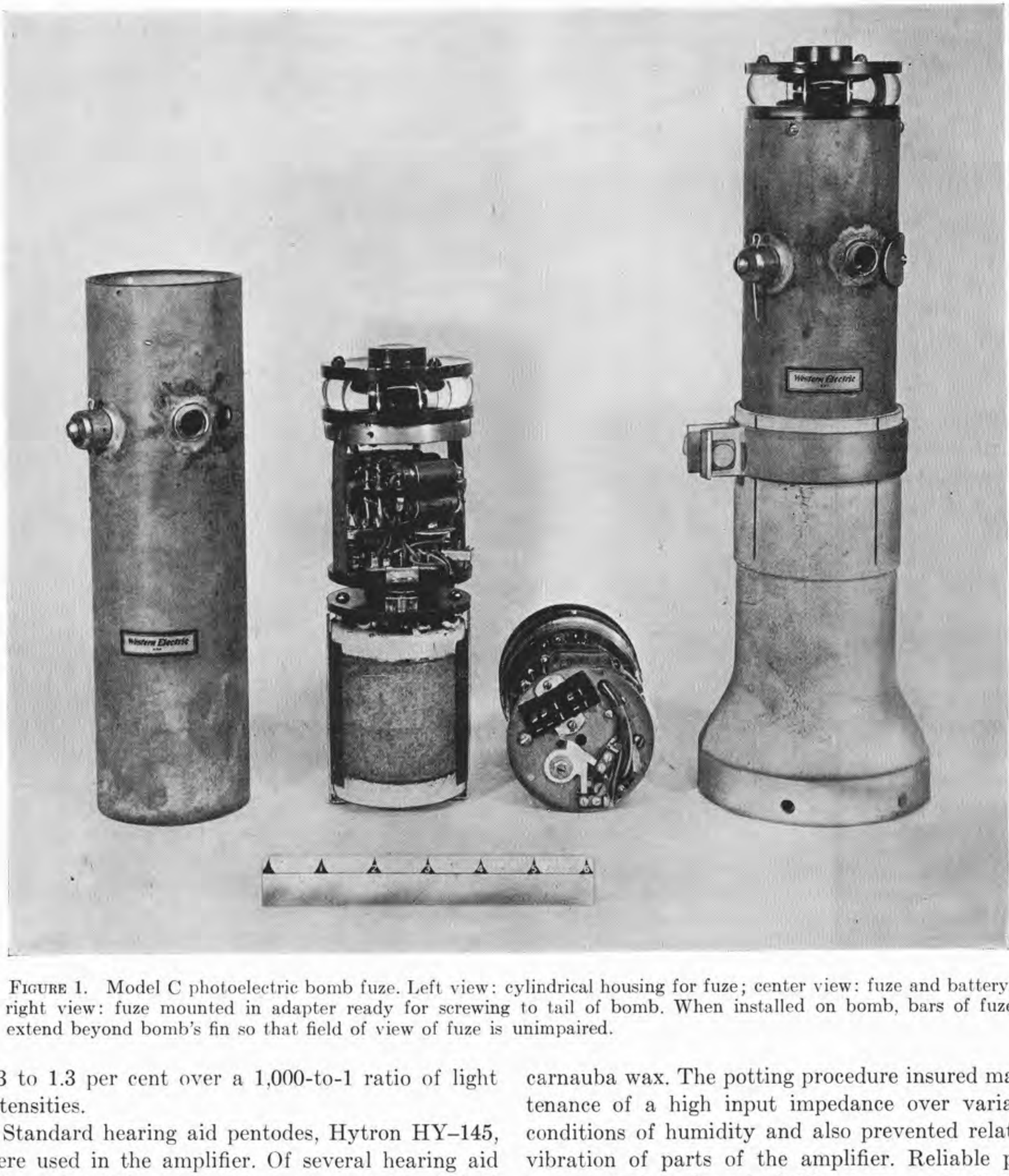


FIGURE 1. Model C photoelectric bomb fuze. Left view: cylindrical housing for fuze; center view: fuze and battery; right view: fuze mounted in adapter ready for screwing to tail of bomb. When installed on bomb, bars of fuze extend beyond bomb's fin so that field of view of fuze is unimpaired.

0.3 to 1.3 per cent over a 1,000-to-1 ratio of light intensities.

Standard hearing aid pentodes, Hytron HY–145, were used in the amplifier. Of several hearing aid tubes tried, this type most nearly met the desired characteristics for the photocell load. The pentodes were tested for microphonic stability and the best ones used in the input stage and the next best in the second stage. A Western Electric D–159778 thyratron was used as the trigger tube.

The entire amplifier was embedded or "potted" in wax consisting of 16 parts ceresin and 1 part carnauba wax. The potting procedure insured maintenance of a high input impedance over variable conditions of humidity and also prevented relative vibration of parts of the amplifier. Reliable performance of the fuzes in field tests was not obtained until the potting procedure was adopted.[1,104]

Power Supply. Electrical power for the vacuum tubes was supplied by dry cells. Three standard penlite cells were connected in parallel for the A battery, to give the required drain of about 300 milliamperes at 1.5 volts. The B battery was built of 80 Type 132 cells built into 4 assemblies of 20

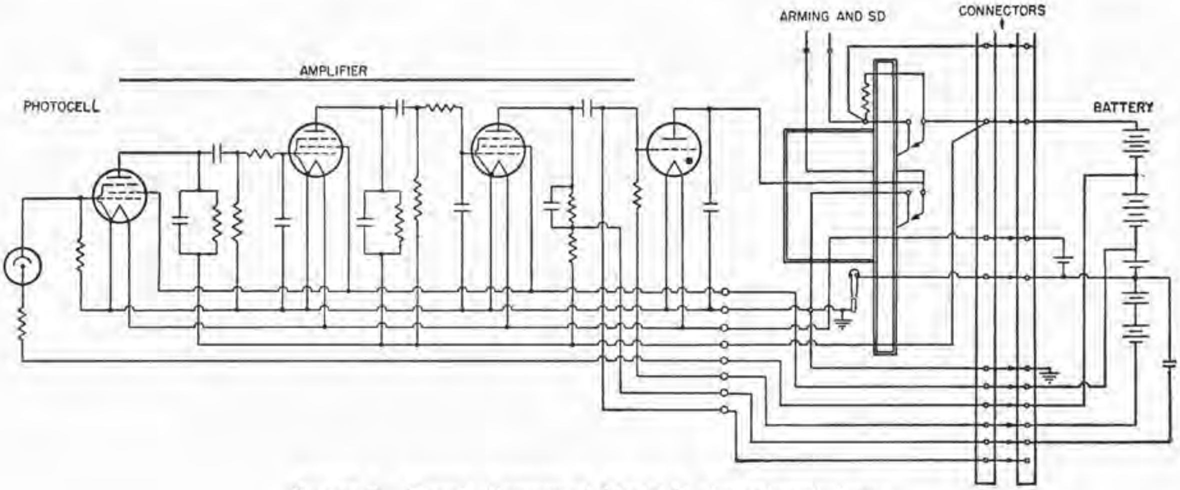


FIGURE 2. Circuit diagram of Model C photoelectric fuze.

cells each. It was tapped to yield voltages of 111, 90, 21, 0, and −9. The B battery, A battery, and a 4-microfarad electrolytic capacitor formed the battery unit designated as Type X604. It was 2⅞ in. in diameter and 3½ in. long.

Arming. The arming system [1,3] consisted of a clockwork which operated a number of electrical contacts. When the bomb was released, the withdrawal of an arming wire set the clockwork in motion, and a switch was closed, which applied voltages to the filaments and plates of the vacuum tubes. Six seconds after release, corresponding to about 400 ft of vertical drop, a high resistor in series with the detonator was shorted, rendering the fuze active. Eighteen seconds after release, another switch closed, firing the detonator. The latter operation occurred after about 5,000 ft of drop. Thus the "live" range of the fuze was between 400 and 5,000 ft below the bomber.

5.2.2 Model BR, or Mark 1, Fuze [3,104]

The Model BR fuze [96,97] followed essentially the same circuit design as was used in the Model C. Variations were in mechanical assembly and arming to allow use on rockets. A photograph of the BR model is shown in Figure 3.

The arming system required the sustained acceleration of the rocket for its operation. The filament and plate supply voltages were connected at the start of setback and, about 0.1 second after the end of setback, the detonator was connected through a resistance-capacitance delay network. Self-destruction [SD] was obtained with a clockwork, started by the setback switch. SD times could be set for either 15 or 30 seconds.

All components in the fuze were required to withstand an acceleration of 2,500g. The pentodes [4,6] used in the Model C were, with minor alterations, satisfactory in this respect. However, new thyratrons and photocells were required. The Bell Telephone Laboratories [BTL] 1278 GY2 thyratron and the Radio Corporation of America [RCA] C–7052 vacuum photocell were used.

In this fuze, the look-forward angle was set at 25 degrees, and the width of the field of view was 5 to 6 degrees.[87] The fuze functioned on a decrease in light intensity of about 1.5 per cent (at the optimum rate of change).

Most of the development work for the BR model was based on field tests with a special test rocket rather than with the British UP rocket. The latter rocket was not available in this country in any appreciable quantity; furthermore, its relatively long burning time (about 1 sec) and high dispersion made target tests difficult to carry out. For these reasons, Division 4 developed and procured a special rocket intended only for use in testing fuzes. This rocket is described in Section 9.1.1. The fuze designed especially for the test rocket was designated Model AR,[3,104] and this fuze provided most of the engineering data for the Model BR.

5.3 T-4 FUZE [84]

5.3.1 General Features

The T–4 fuze for the M–8 rocket was a simplified and smaller version of the BR fuze. The major

FIGURE 3. Model BR photoelectric rocket fuze. Left, completely assembled fuze ready for installation on rocket. Next, from left to right, electronic assembly showing arming switch, cylindrical housing, battery, and rocket ogive which encloses battery.

simplification was in the use of a thyrite [114,115] resistance element for the photocell load, followed by only one stage of amplification. A smaller, more compact battery [78] developed by the National Carbon Company became available for the power supply. The fuze and its major subassemblies are shown in Figure 2 of Chapter 3.

The look-forward angle was set at 22.5 degrees and the width of the field of view at 4.5 degrees. Sensitivity was such that operation would occur on a 1.5 per cent change in light intensity. This corresponded approximately to the signal obtained in passing a medium bomber about 70 ft away.

The nose, MC–380 ( ), was completely sealed [85] and contained the electrical components, consisting of the photocell-lens combination, the amplifier, and the thyratron. The parentheses contained the code letter, indicating the manufacturer; the letters A, B, C, and D indicating noses made by the Western Electric Company, the Westinghouse Electric and Manufacturing Company, the Rudolph Wurlitzer Corporation, and the Philco Corporation, respectively. The noses were interchangeable in the fuze. The front part of the nose formed the conical ogive for the rocket to which the fuze was assembled. The conical portion contained the pseudocylindrical Lucite lens. At the base of the conical portion was a shoulder [85] which contained slots for the wrench used to tighten the fuze in the rocket. The base of the nose contained two sets of threads. The smaller diameter threads were for assembly to the booster housing. The larger diameter threads were used for assembly to the rocket. Protruding from the base of the nose were the electric contact pins for connection to the battery. The base of the MC–380 nose also contained a longitudinal red guide mark for proper alignment and assembly to the battery. Along the center of the guide mark was a groove used to secure proper alignment when the fuze was assembled in darkness.

The battery, BA–75,[78] provided the electric power supply for operation of the fuze. It was encased in a black bakelite cylinder. The upper plate contained a 7-pin socket to receive the nose pins. The bottom plate contained a 6-pin socket to receive the switch pins. This plate had a notch to assist in securing proper assembly to the switch in darkness.

The switch, SW–230,[77] contained the mechanical and electrical devices necessary to activate and arm the fuze, an electric detonator, and a powder train interrupter for safety during handling and launching. Protruding from a fiber terminal disk at the top of the switch were the electrical contact pins for connecting to the battery. There was a metal cylindrical case around the switch to protect the internal mechanism and explosive. At the bottom of the switch was a thick metal plate with a circular hole concentric with the switch. After the switch was armed, the tetryl pellet which detonated the booster charge was lined up with this hole. Arming occurred approximately 1 sec after launching, at which time the rocket would be about 500 to 600 ft [113] ahead of the launcher.

The booster housing, M–381,[85] also acted as the encasing can for the battery and switch. It screwed onto the smaller threads of the fuze nose. In the bottom of the housing was a chamber containing a tetryl booster charge. There was a metal partition separating the booster from the switch. In the center of this partition was a circular hole which lined up with the hole in the switch plate. It was necessary to control the length of the booster housing in order to allow only a very small clearance [98] between the tetryl booster and the bottom of the fuze well.

The battery, switch, and housing were common to the T–4 and T–5 fuzes.[c]

The table below lists the weights and dimensions of the components of the Fuze, Rocket, PD, T–4.[113]

Although the nose, the battery, and the switch were all tested when made, the possibility existed that they might no longer be in operating condition when the time came for the fuze to be used. The probability that the switch might have become defective without some visible damage having occurred to its case was extremely small, and the probability that the nose had become defective was only slightly larger. However, the battery had only a limited shelf life, so it was necessary to test it before assembling the fuze. Test Equipment IE–28 [90,112] was therefore designed to test the components of the fuze under field conditions. These tests in the field were not so precise as the laboratory tests, but they permitted the rejection of fuze components which might have caused the fuze to malfunction. The new nature of electronic fuzes as ordnance items was a considerable factor in the decision to provide a field test set. Such test sets were not considered necessary for later fuzes (generator-powered radio fuzes).

5.3.2 Mechanical Layout

A picture of a cutaway model of the T–4 fuze is shown as Figure 4. It is completely assembled with the exception of the amplifier, which has not been potted, and the explosive booster, which has not been included. The four parts of the fuze, namely the MC–380 nose, the battery, the switch, and the booster housing, are clearly shown. The nose, MC–380, will be described in this section.

The inner surface of the Lucite lens is coated with an optical black paint,[50] except for a narrow slit. The light incident on the lens from the look-forward

Unit	Average Weight (lb)	Diameter (in.)	Length Assembled (in.)	Thread
Nose MC–380( )	0.90	3.187 ± 0.005	3.3123 max	3.000–16–NS–2
Battery BA–75	0.60	2.600 − 0.015	2.312 − 0.020	
Switch SW–230( )	0.54	2.600 − 0.015	1.282 − 0.010	
Booster housing M–381	0.50	2.875 + 0.010	4.964 max	2.706–16–NS–2
Assembled PD, T–4	2.54	3.187 ± 0.005	7.567 max	
Depth inside rocket, M–8 or M–9 fuze well			5.250 min	
Length of fuze outside rocket			2.3125 max	

c Reference is made to Division 4, Volume 1, for further details on the design of these components.

angle of 22.5 degrees is focused through the slit onto the photocell cathode. The outer surface of the lens is recessed beneath the surface of the ogive of the nose, formed by the nose cap and the amplifier housing, in order to protect the lens. A plastic photoelectric cell support is designed with very close tolerances so that the cathode will receive the light focused by the lens. The photoelectric cell support also insulates the photoelectric cell cathode from the housing, which acts as the electrical ground. The nose shield is fastened to the lens with machine screws which go into threaded holes. These holes do not extend into the field of view of the lens. A spring is compressed between the nose shield and the photocell, and thus keeps the photocell seated in its proper position. The photocell anode is insulated from the spring by a fiber insulating button. It is apparent from Figure 4, which shows the amplifier and the thyratron within the amplifier housing, that most of the space was wasted and had to be filled with the potting material; however, it was necessary to use the same housing as in the MC–382 nose for the T–5 radio proximity fuze, which required all that space.

The nose cap was kept at ground potential in order to eliminate the possibility of the electron path within the photocell being affected by the large static charge which might otherwise build up on the nose in flight. It was therefore necessary that two wires pass through the field of view, one to ground the nose cap, and the other to keep the photocell anode at B+ potential. It was required [84] that these wires be bare within the field of view and be not larger than No. 28 B&S gauge.

The slit was made on the inner surface of the Lucite lens in the MC–380(B), (C), and (D). In the MC–380(A), the slit was painted on the glass walls of the photocell.[108] If the sensitivity of the fuze was to be uniform in all directions, it was necessary that the edges of the slit be very clean and that the slit width be kept uniform throughout its length. Very uniform slits could be obtained by painting the Lucite, but it was found that the paint contained solvents which released strains in the Lucite lens, causing fine cracks to appear. The lens gradually deteriorated until it was no longer usable. Consequently, it was necessary to find a solvent for the paint pigment which would not cause this crazing of the Lucite.[61,101,102] Although painting the slit on the photocell eliminated the crazing problem, it emphasized the problems involved in manufacturing the photocell. The glass wall was not always concentric with the cathode and was not always circular. The resultant variations in the position of the slit with respect to the cathode produced a nonuniform sensitivity pattern for the lens-slit-photocell system. As the slit was closer to the cathode when it was painted on the photocell wall, a tilted cathode

FIGURE 4. Cutaway of T–4 photoelectric fuze showing placement of components.

caused a greater nonuniformity in the optical sensitivity pattern when this method was used than when the slit was painted on the lens.

The amplifier was potted with the same ceresin-carnauba wax mixture used in the Model C fuze. Other mixtures with better antishrinkage properties were tried,[16] but none had as good electrical properties as the wax. In a postproduction development, with a variation of T–4 designated as RPEB–2,[34,35] it was found that a Glidden compound [27,28] had satisfactory electrical and mechanical properties.

5.3.3 Electrical Layout

The electric circuit used in the nose MC–380 is shown in Figure 5.

In order to secure the proper amplifier characteristics [14,19] when pentodes from different manufacturers [23] were used, slightly different values of resistance and capacitance were necessary. These values are shown in Table 1.[34]

The optical parts of the fuze were designed to be included within the fuze ogive. The input lead from the photocell to the amplifier had to be kept quite short in order to minimize possible leakage effects because of the high impedance of the network. It was therefore necessary that the amplifier be as close as possible to the photocell. The electric detonator and the booster were placed at the bottom of the fuze to start the explosion. The detonator had to be part of the switch, as it was required that an interrupted powder train be used, and the switch contained the moving parts which could be used to move the detonator to line up the explosive train at arming. Leads to the detonator were brought through the battery, which occupied the space between the amplifier and the switch.

Noses MC–380(A), (B), (C), and (D) contained the electric self-destruction network, whereas noses MC–380(D), (F), (G), and (H) did not.[112,113] These latter noses could be assembled in fuzes which would destroy themselves if switches SW–200(B) or SW–230(B) were used. These switches contained a mechanical self-destruction contact set to operate 6 seconds after firing. The switch shown in Figure 5 is the SW–200. Switch SW–230 contained an electric arming delay [d] which started to operate after mechanical arming had occurred. A resistor was mounted in the switch next to pin No. 6, so that the detonator firing condenser charged up through this resistor.

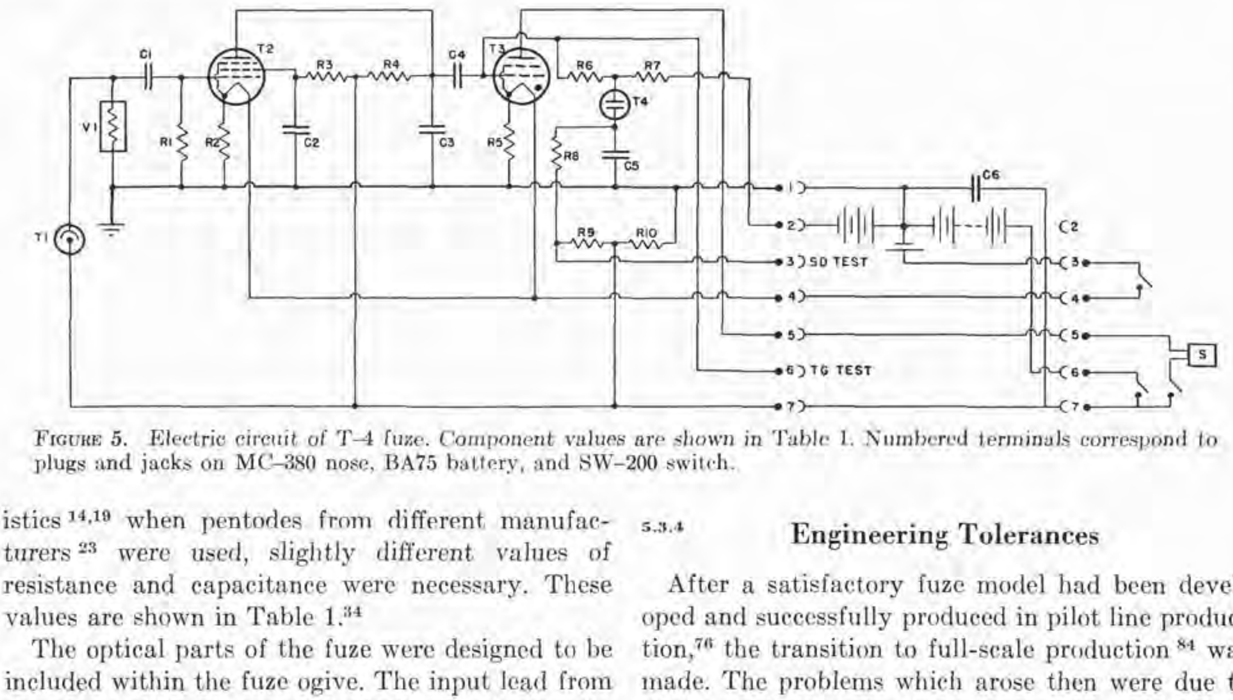


FIGURE 5. Electric circuit of T–4 fuze. Component values are shown in Table 1. Numbered terminals correspond to plugs and jacks on MC–380 nose, BA75 battery, and SW–200 switch.

5.3.4 Engineering Tolerances

After a satisfactory fuze model had been developed and successfully produced in pilot line production,[76] the transition to full-scale production [84] was made. The problems which arose then were due to the impossibility of making any two items identical. On the basis of the experience gained during pilot production, tentative specifications [77-86,88,89,91-95] for the Fuze, Rocket, PD, T–4 were written. The tolerances allowed in the various components and subassemblies, and in the complete fuze, were necessarily compromises between fuze quality and fuze quantity. Wide tolerances would permit the production and acceptance of many more fuzes, but, obviously,

[d] The action of this electric arming mechanism is explained in Division 4, Volume 1, Section 3.3.

TABLE 1. Component values.*

Components	MC–380			RPEB–2			
T1	936	†	†	1P24	†	†	†
T2	145ZT	QF206	SA781	145ZT	QF206	SA781A	GE QF206
T3 ‡	ZG489	GY2	SA782B	SA782B	†	†	†
T4	NE23	†	†	†	†	†	†
C1	0.0005	†	†	0.005	†	†	†
C2	0.02	0.02	0.02	0.01	0.003	0.005	0.005
C3	0.001	†	†	†	†	†	†
C4	0.002	†	†	†	†	†	†
C5	0.25	†	†	†	†	†	†
C6	1.7	†	†	†	†	†	†
R1	90	†	†	10	†	†	†
R2 §	none	7.5 Ω	7.5 Ω	none	5 Ω	5 Ω	5 Ω
R3	4	†	†	6.8	10	10	10
R4	1	†	†	2.2	2	2	2
R5 ‖	none	none	2 Ω	2 Ω	†	†	†
R6	2	†	†	†	†	†	†
R7	0.1	†	†	†	†	†	†
R8	35	†	†	†	†	†	†
R9	2	†	†	†	†	†	†
R10	2	†	†	†	†	†	†
V1 ¶	Varistor, class L, M, or N			Varistor, class M, N, or high L			

* All capacitances in microfarads; all resistances in megohms, except where indicated.
† Component value does not change.
‡ Any thyratron may be used with any pentode.
§ Pentode filament resistor.
‖ Thyratron filament resistor.
¶ These classes are defined in terms of the varistor current for a potential drop of 110 volts; class L passes 50 to 90 microamperes, class M passes 90 to 150 microamperes, and class N passes 150 to 300 microamperes.

fuze quality would suffer. The basic problem was that it was not known what the characteristics of a perfect fuze would be. Because of the exigencies of World War II, it was necessary to start production before these ideal characteristics could be determined. The additional experience to be gained from quantity production and testing was required before it could be definitely determined what tolerances would be permissible for the various fuze parts. This section will deal with the subassemblies in the nose MC–380, and the separate components will be discussed in the section on components at the end of this chapter.

Optical System. The variations in the optical system of the fuze arose from the variations in the lens, in the slit, and in the photocell, and in the mechanical accuracy with which these components were assembled. It was found that the angular width at which the light transmission of the system was less than 5 per cent of its maximum transmission could easily be kept within 10 degrees when the slit was painted on the Lucite. However, a larger tolerance had to be allowed in order to include the model with the slit on the photocell. Some of the problems were that the glass wall was not a true cylinder, or that it did not form a right circular cylinder, or that the photocell cathode was not axially centered. The tolerances allowed in the photocell manufacture are discussed in Section 5.5.

Studies[19] were made to determine the limits for the various components so that a fuze would work even though it contained several components which just met the specifications. The various subassemblies and the complete nose were also tested to make certain that these variations would not affect fuze performance. Some tests were made of the uniformity of the optical system of the fuze by simulating the operating conditions. In general, the fuze saw a half-ring of sky of fairly uniform brightness and a half-ring of ground of roughly half the sky brightness.[54] In these tests, the nose was mounted axially inside a cylinder, half of which was white and half of which was black. The nose was then rotated, and the photocell current was measured. The ratio between the minimum current and the maximum current formed a valid criterion of the uniformity of the optical system. In over half of the fuzes, the uniformity was 95 per cent or better, and, in over 90 per cent, it was better than 85 per cent.[54]

Photocell Load Resistor.[38,41] As has been described in Chapter 4 of this volume, it was necessary to use a nonlinear element [1,3] in the fuze in order that the voltage signal at the thyratron grid be proportional to the percentage light signal input to the photocell, and independent of the steady background light level. It was shown that an element with a logarithmic response would ideally meet these criteria. In the T-4 fuze, use was made of a nonlinear resistive element, known commercially as "varistor" [114] if order to determine what range of values of varistors should be used in conjunction with the photocells being used, taking account of manufacturing variations in both the varistors and the photocells, graphical calculations [42] were made in which all the possible values of the two fuze components were covered. The voltage output for a 1 per cent light signal was determined from these graphs for the different possible varistors. Figure 6 shows a set of these calculated curves for $n = 5$. The abscissa scales correspond to an average photocell, one only half as sensitive, and one twice as sensitive. The curve for the varistor with a resistance of 50 megohms at 1

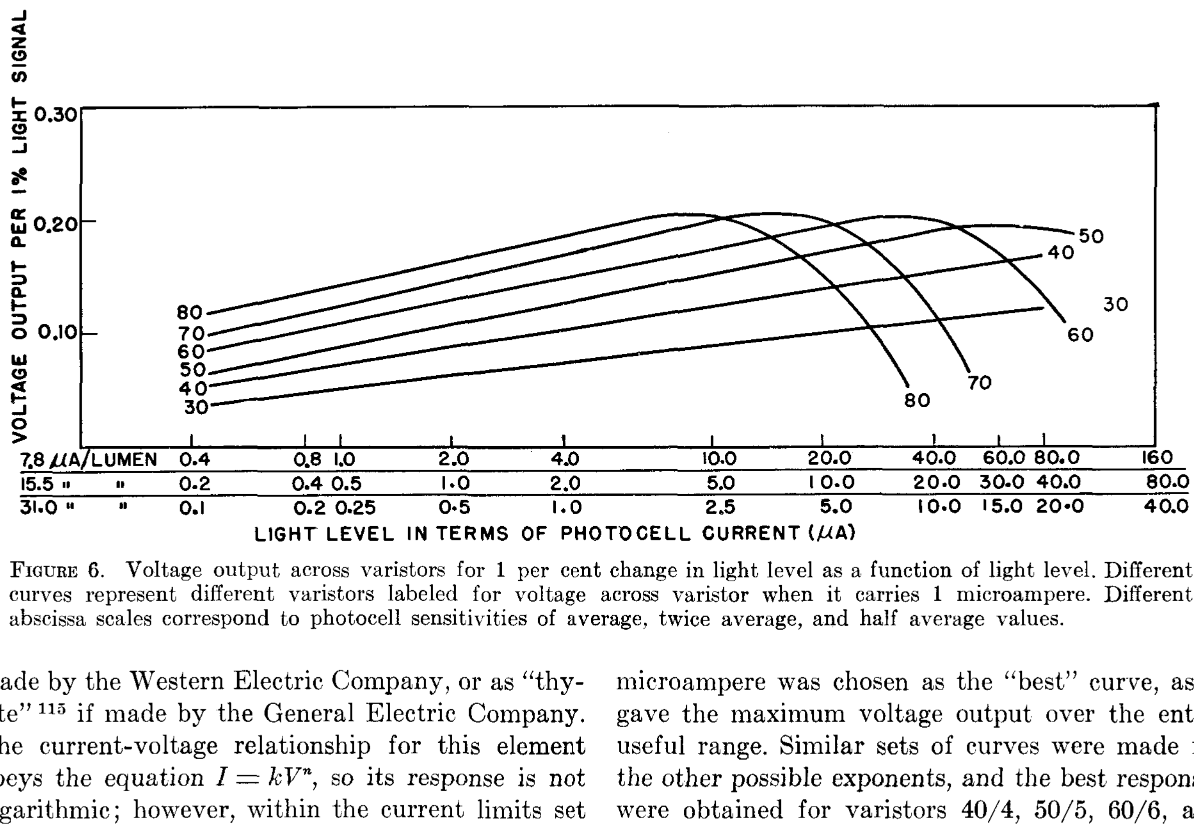


FIGURE 6. Voltage output across varistors for 1 per cent change in light level as a function of light level. Different curves represent different varistors labeled for voltage across varistor when it carries 1 microampere. Different abscissa scales correspond to photocell sensitivities of average, twice average, and half average values.

made by the Western Electric Company, or as "thyrite" [115] if made by the General Electric Company. The current-voltage relationship for this element obeys the equation $I = kV^n$, so its response is not logarithmic; however, within the current limits set by the photocell used and the normal variations of daylight,[22] the response approximates a logarithmic curve adequately enough for use in the fuze.

The nonlinear element, or varistor as it will be called hereafter, acted as a variable load resistor for the photocell. To specify the varistor, k and n in the equation $I = kV^n$ must be given. In the work on the photoelectric proximity fuze, the two characteristics [42] used to describe a varistor have been its exponent, n, and the ratio, V/I, in megohms, when a current of 1 microampere is flowing through it. In microampere was chosen as the "best" curve, as it gave the maximum voltage output over the entire useful range. Similar sets of curves were made for the other possible exponents, and the best responses were obtained for varistors 40/4, 50/5, 60/6, and 70/7, where the numerator is the resistance in megohms for a 1-microampere current and the denominator is the exponent n. Figure 7 shows the voltage output from the photocell-varistor network for a 1 per cent light signal for each of these varistors. As the impedance of a varistor for a varying current is $1/n$ times its resistance for a constant current, it is evident that the a-c impedance is 10 megohms at 1 microampere for each of the varistors chosen as having the most suitable characteristics. The normal background light level was 8 microamperes

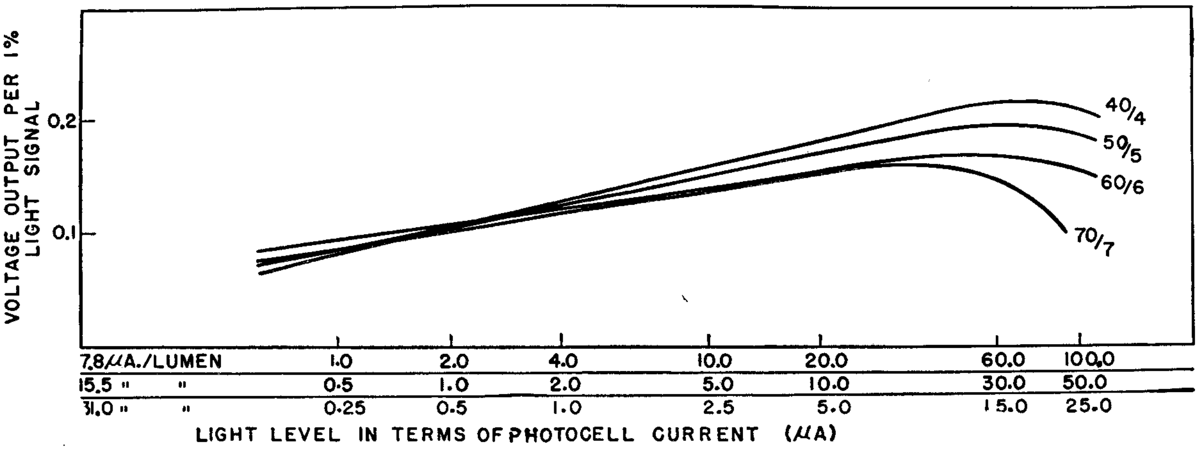


FIGURE 7. Voltage output across four different varistors as function of light level. Ordinate and abscissa scales are as in Figure 6. See text for description of varistors.

in the standard lens-photocell combination, so calculations were made[42] to determine if a reference current level somewhere between 8 microamperes and 1 microampere, say at 4 microamperes, might be better than the 1-microampere level for determining the equality of varistor impedances for alternating current. It was found that the spread of output voltages from the photocell-varistor combination for a 1 per cent light signal, using varistors whose a-c impedances were equal to 4 microamperes, was greater than when the impedances were equal at 1 microampere.

As a result of these investigations, it was decided that a satisfactory range in varistor values existed which would provide adequate output voltages over the entire range in light levels even after allowing for a wide variation in photocell sensitivities. The voltage-current curves for varistors 40/4, 50/5, 60/6, and 70/7 are shown in Figure 8. Any varistors whose voltage-current curves were within these limits between 0.4 microampere and 24 microamperes were acceptable. These current values covered the range of photoelectric currents produced in any acceptable lens-photocell combination[76,84] by the background light level during daylight.

At low light levels, the peak of the frequency response curve of the amplifier is shifted toward lower frequencies as the light level is decreased.[29] This effect arises because of the capacitance associated with the nonlinear resistance. Capacitances of the General Electric thyrites have been measured and found to vary from 25 to 55 micromicrofarads,

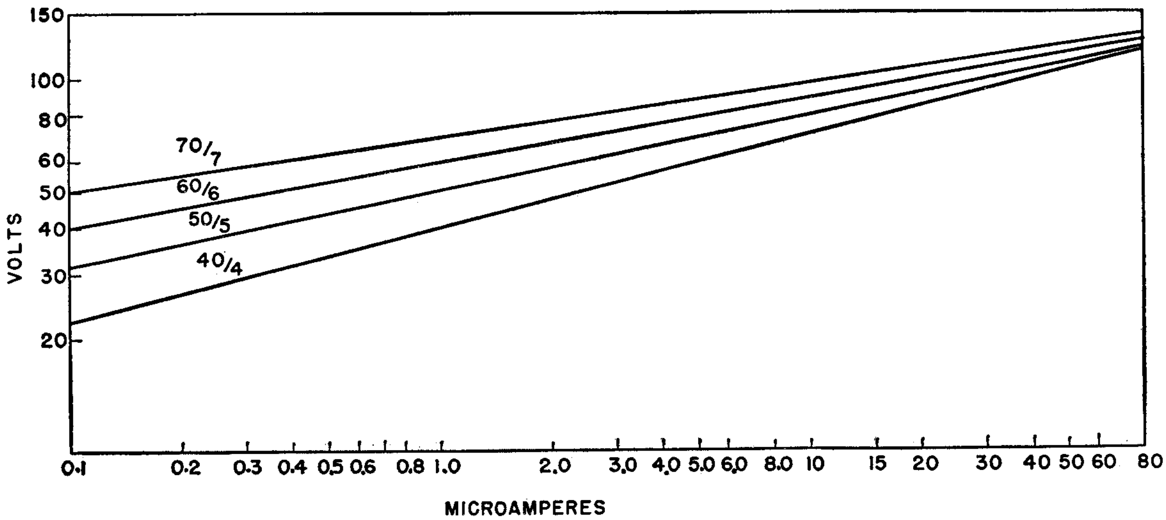


FIGURE 8. Voltage-current characteristics of four varistors. See text for method of designating varistors.

[redacted]

with an average value of about 30 micromicrofarads. At 120 c, the impedance of a 30-micromicrofarad capacitance is 44 megohms. The effect of this shunt is important only at low light levels, as the a-c impedance of the nonlinear resistance is small in comparison to 44 megohms except for small photocurrents. As the current decreases, the resistance of the varistor increases exponentially, while its capacitance remains virtually constant. Thus there is a decrease in the amplification of the unit as the light level is decreased for a signal at any frequency. Overall sensitivity involves the changing effects of both the amplifier and the nonlinear input resistor and is obtained most readily by the method described in Section 6.2.3 for threshold measurement (inverse of sensitivity). Figure 9 gives the threshold in terms of per cent light signal for an average unit for a 60-c light signal, as a function of the background light level.[68] The thresholds increase slowly as the light level is decreased from 3 times the normal background level to one-quarter of the normal light level. Below this level, the thresholds increase quite rapidly as the light level is decreased.

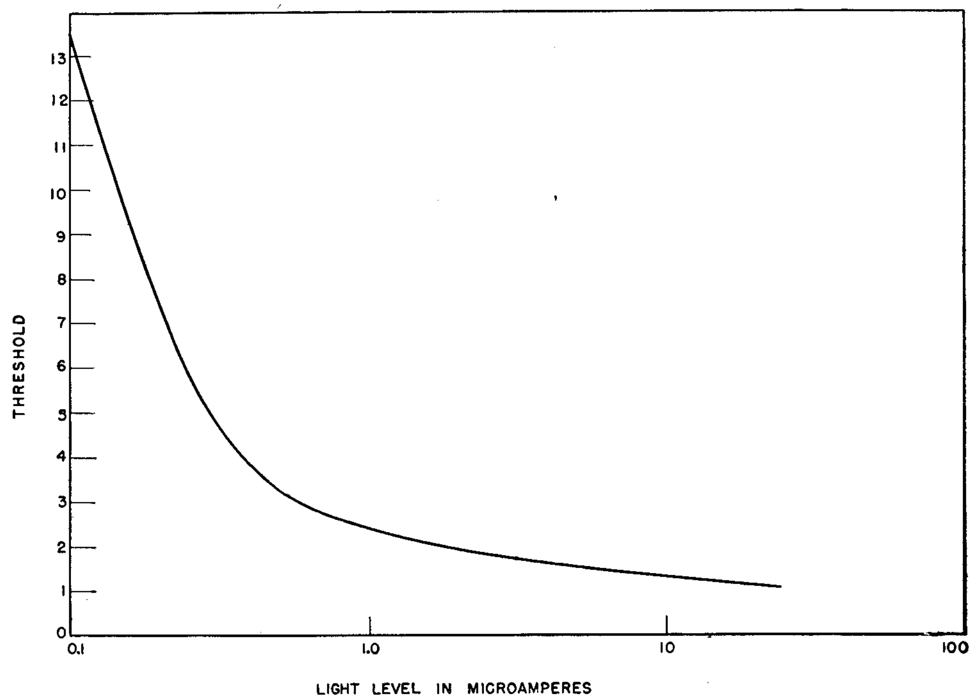


FIGURE 9. Threshold (inverse sensitivity) of T–4 fuze as function of light level.

Effect of Supply Voltage Variations. The basic design of the amplifier was discussed in Chapter 2 of this volume. The circuit diagram of the amplifier is included in Figure 5, which shows the electric circuit diagram for the entire fuze. The frequency response curve for the amplifier,[14] indicating the relative amplitude of the output signal as a function of frequency, was shown in Figure 15 of Chapter 4. This curve was the average curve for two amplifiers built with accurately chosen components. The nominal supply voltages of 1.5 volts for the A supply and 138 volts for the B supply were used. In operation, the fuze battery voltages were usually less than these nominal values, and measurements were made to determine how low the actual voltages could be without unduly affecting proper fuze functions. As the voltage decreased from 1.50 volts, there was no reduction in gain until the filament potential was reduced to 1.15 volts.[4] Thereafter, the gain fell rapidly. At 1.00 volt, the average gain was 92 per cent of maximum, and, at 0.90 volt, the average gain was only 78 per cent of maximum.

Sensitivity as a Function of Light Level. Although the ideal photoelectric proximity fuze is independent of the light level, this goal was not possible with the simplified circuit used in the T–4. It was decided that the small variation in fuze sensitivity as a function of light level was less important than simplicity in construction. At the normal light level

[redacted]

(see Chapter 4), a light signal of less than 0.8 per cent would fire the fuze, whereas, at a light level only one-eighth as bright, a 2.2 per cent light signal is necessary.

Input Impedance. The impedance [29] of each of the components [43] used in the input circuit was necessarily quite high because of the very high impedance of the vacuum photocell used. The effect of a light signal incident on the photocell was to cause a current signal to flow through the impedance network. The magnitude of the current pulse was practically independent of the impedance values, so the larger the input impedance, Z, of the pentode [5] was, the larger the voltage signal at the pentode grid would be. In the average fuze, the voltage signal required to cause the amplifier to fire the thyratron was about 0.1 volt peak. The amplifier gain at the signal frequency was about 40, and the thyratron holding bias was between 3 and 4 volts. The frequency at which the pentode network had its maximum amplification was about 130 c. At this frequency, the impedance of the 0.0005-microfarad condenser was about 2.5 megohms. The input impedance of a good pentode, as used in the amplifier, was about 20 megohms.[53] One of the major problems which arose in manufacturing the nose, MC-380, was the decrease in the input impedance [29] of the pentodes with age. Gas would be evolved in the tube in storage because of imperfect evacuation of the gas during the manufacture of the tube, and the input impedance of the tube would decrease tremendously.[5] In some tubes there was an impedance decrease by a factor of about 15, which caused a decrease in sensitivity of the fuze by a factor of only 2 at normal light levels, but at low light levels by a factor of 5.[29] The gas in these tubes would be absorbed by the getter if the tube were operated for a few minutes before using the fuze, but provision for such operation would be difficult in Service use. In the condenser-powered fuze,[8,9] described in Section 5.4, a method to overcome this difficulty is discussed. Large plate and screen resistors were used, so that the electron current in the tube, which might cause ionization of any gas present, was decreased. Much more important, however, was the result that, with the large series resistors, the electrode potentials were below the minimum ionization potential for any gas that might be in the tube, so only minute quantities of ionized gas were possible.

Another method of reducing the input impedance problem was the use of more sensitive photocells and lower impedance varistors. Some of these changes were incorporated in the post-production model of the RPEB-2.[34,35]

5.4 EXPERIMENTAL MODELS

5.4.1 Generator-Powered Rocket Fuzes [RPEG]

In order to eliminate the deficiencies of the battery power supply of the T-4 fuze, developments were initiated to replace the battery in the fuze by a generator power supply.[17,108] Designs were adapted to the exterior dimensions of the T-4 fuze in order that the new fuze, designated RPEG (Rocket, PE, Generator), could replace it.

The power supply for the photoelectric-type fuze had to perform under the same general conditions as that for the radio-type fuze.[e] The same qualities of long storage life, mechanical and electrical stability, independence of ambient conditions during the service period or storage, ruggedness, small size, and simplicity of production were desired. Requirements differed only in that the PE electronic assembly had a significantly smaller electric power demand than the radio-type unit. The potentials involved were the same in the two cases, 130 to 150 volts d-c for plate supply, 1.3 to 1.5 volts a-c for filament supply, and −6.0 to −7.5 volts d-c for the C bias. However, the lighter current drain of the photoelectric unit gave an aggregate power requirement of less than 1 watt in service as compared with approximately 5 watts for the radio unit.

This smaller power requirement rendered the delayed service and low-temperature deficiencies of dry batteries less serious for the photoelectric unit than for the radio unit and also permitted consideration of power supply systems which were not practical for the radio unit (cf condenser-powered fuze, Section 5.4.3). However, the ultimate solution of the power supply problem appeared to lie in the use of a rotary permanent-magnet alternator, wind-driven by the flight of the projectile.[f] Experimental development was done on generator-powered photoelectric fuze RPEG for use with the M-8 rocket [17] and generator-powered photoelectric fuze BPEG for use on bombs [108] which accepted the M-103 point-detonating fuze.

[e] These requirements are discussed in detail in Division 4, Volume 1, Section 3.4.

[f] Cf Division 4, Volume 1, Section 3.4.

[redacted]

In both cases, the necessity of mounting the photoelectric cell and its optical system centrally at the nose of the fuze complicated the overall design. This precluded the use of a nose-mounted propeller with a central drive shaft to the generator, or of a central air duct to a turbine mounted at the base of the fuze, the designs which were favored in the generator-powered radio units (see Figures 2 and 3, Chapter 1). In consequence, both RPEG and BPEG made use of peripherally located air scoops and ducts, with rim-driven turbogenerator assemblies mounted at the base of the fuze.

The general design followed in the development of RPEG is shown in the schematic section drawing of Figure 10. The nucleus of the unit was the centrally located metal can which housed the electronic assembly and the power supply. The metal nose cap and the annular Lucite lens completed its foresection. The rotor of the turbogenerator was carried on a stationary stub shaft projecting from the rear of the assembly.

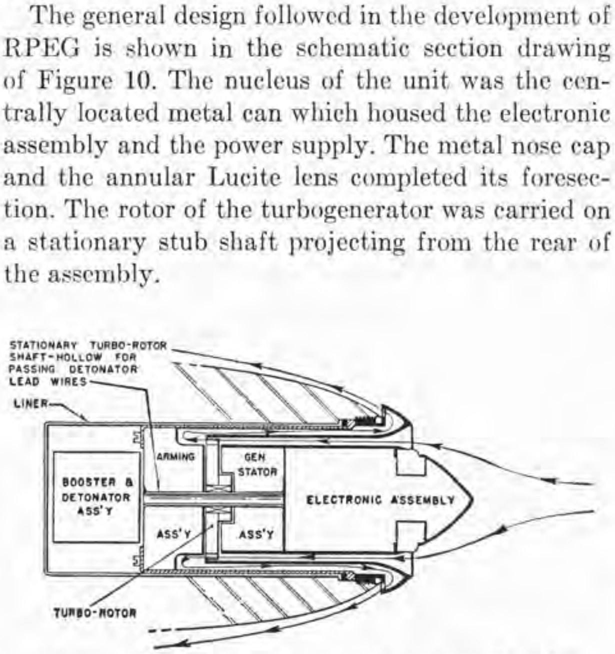


FIGURE 10. Photoelectric generator-powered rocket fuze, RPEG. Axial section is shown schematically. Path of air through ducts and driver turbine is indicated by arrows.

A tubular metal cowl, flared toward the nose end, was mounted coaxially on the electronic power supply container, spaced out from it by three $\frac{1}{8}$-in. bosses to provide an air intake duct. These parts are shown in Figure 11. A larger tubular metal piece was mounted coaxially and $\frac{1}{8}$ in. out from the intake cowl to provide a counterflow exhaust duct. This is shown in Figure 10, where the arrows indicate the airflow through the duct system and the turbine blades. The outer tube also served as a mounting for the arming and detonator assembly. The RPEG, mounted in a rocket, is shown in Figure 3, Chapter 3.

The generator and electronic assembly of an experimental model are shown in Figure 12. The electronic assembly was essentially that of the MC–380, rearranged and reduced in size to the required 2 in. OD. The generator consisted of A and B windings distributed on three bobbins, each mounted on a U-shaped lamination stack as shown. The turborotor

FIGURE 11. Photoelectric generator-powered rocket fuze, RPEG. At left, experimental model with improvised housing for arming switch SW–200 attached at rear. At center, electronic and power supply assembly. At right, cowling member for directing air to and from turbine.

was a bakelite disk $2\frac{3}{8}$ in. OD and $\frac{5}{16}$ in. thick. The turbine blades, 26 in number, were molded on its periphery. Three bars of Alnico III magnet steel, $\frac{1}{4}$ in. square in cross section and 1 in. long, were molded as inserts in the turborotor. After molding, these were magnetized to activate the magnetic circuit of the generator.

The circuit for regulating the output voltages of the generator against variations due to change in its rotational speed, the B-supply rectifier, and the filter were of the same type as were used in the radio-type fuzes.[g]

The RPEG project was included in the general termination of work on PE fuzes. The photographs shown here represent the status of model production at the termination date. The model described (Figure 12) had passed a number of laboratory tests but had not been subjected to field tests on rockets.

A number of projected improvements had not yet reached model production at the termination date. These included:

1. A single-coil generator utilizing a magnetic stator stamped as part of the steel can which housed the electronic assembly. The magnetic rotor was a

[g] These are described in detail in Division 4, Volume 1, Section 3.4.

disk of Alnico II, 1 in. OD by ¼ in. thick, molded on the face of the turborotor and mounted reentrant into the stator as shown in Figure 10.

2. An electrically redesigned amplifier having higher peak gain and a much narrower passband, with upper cutoff frequency below the rotational frequency of the generator during service.[h]

predetermined number of turns. If setback force were removed prior to this locking, the clutch nut returned to the unarmed position.

Although no working models were produced for testing, a workable basic design for RPEG appeared to have been completed at project termination.

FIGURE 12. Photoelectric generator-powered rocket fuze, RPEG. At left, electronic and power supply assembly. At right, unit disassembled to show electronic and generator stator subassembly and turborotor. (Note detonator leads which are fed through hollow shaft.)

3. An arming system actuated by the combination of air travel and setback. This was to operate through a clutch from the back face of the turborotor. The clutch used a spring-biased split nut on a ratchet thread and engaged under the action of setback forces. It was locked into engagement by a

[h] Cf amplifier design for generator-powered radio proximity fuzes, Division 4, Volume 1, Chapter 3.

5.4.2 Generator-Powered Bomb Fuzes [BPEG]

The generator-powered PE bomb fuze [BPEG] [108] was developed for use on bombs which mounted the M-103 point-detonating fuze. This unit is shown in Figure 4, Chapter 3. The small-diameter cylindrical section seated into the bomb fuze well, secured by a 2x12-in. thread at its upper end. The larger section of the fuze, 3¼ in. OD by 4¾ in. long, projected from the nose of the bomb. Figure 13 shows the unit disassembled into its principal subassemblies. The electronic assembly, including photocell and lens, was mounted in the nose section of the unit. Immediately behind were the generator and power supply.

FIGURE 13. Photoelectric generator-powered bomb fuze, BPEG, disassembled into principal subassemblies. At top, electronic unit, with photocell and lens. At left, power supply, arming and detonator assembly. At center, unit housing. At right, air director cowl. Below, unit base housing and, at right, insulating washer. (Photograph by Bell Telephone Laboratories.)

Arming, detonator, and booster elements were housed in the rear part of the fuze well section. Since the turbine was not mounted within the fuze well, no counterflow exhaust duct was required. Intake and exhaust ports for the turbine cavity can be seen in the cast brass housing which is centrally located in Figure 13. The tubular brass cowl (seen at right, center, in Figure 13) was assembled around the cast housing to provide a peripheral intake scoop and exhaust apron for the ports.

The BPEG power supply, in respect to circuit design, components, and operating characteristics, was essentially identical with that of the P–4 radio fuze (Bell Telephone Laboratories designation).[i]

As shown in Chapter 8, a small sample of BPEG fuzes gave good performance in field tests on bombs.

5.4.3 Condenser-Powered Fuzes

It was found that because the PE fuze operated on a very low B and C current drain, it was feasible to employ for the B and C and thyratron plate supplies a pair of capacitors which were charged just before the unit was fired.[8,9] The condensers are not subject to the limitations of temperature and shelf life as are batteries and thus are simpler, cheaper, and easier to procure.

Besides the substitution of the charged condensers for the batteries, these units incorporated other advantages not necessarily characteristic of the condenser-driven circuit alone. The circuit diagram is shown in Figure 14. The high impedance of the plate and screen load resistors caused the pentode to operate with such low plate and screen voltages that the effect of the residual gas in the pentodes,[5] which led to some difficulties in the T–4, was eliminated. The magnitude of the thyratron grid bias was proportional to the current drain through the photocell and the pentode. As the charge was drained from the condenser, the diminution of the current through the pentode reduced the thyratron bias, making the unit progressively more sensitive after firing. This was considered an advantage because a unit which is fired at the more distant targets is likely to require greater sensitivity for proper functioning. Ten or twelve seconds after firing, the bias would become so low that the thyratron fired in the absence of signal, and any need for an auxiliary circuit for self-destruction was eliminated. The unit was far superior to the T–4 in its threshold flatness characteristic; that is, its overall sensitivity did not vary as much with light level. At lower light levels, the lower photocurrent supplied lower thyratron holding bias, and this tended to compensate for the loss in amplifier sensitivity at the low light levels.

The condenser-powered fuzes which were built used the same housings as the T–4 fuze. As shown in Chapter 8, field tests [12] of the modified unit were very satisfactory.

Reserve Batteries.[64] For use with the condenser-

[i] This is described in Division 4, Volume 1, Section 3.4

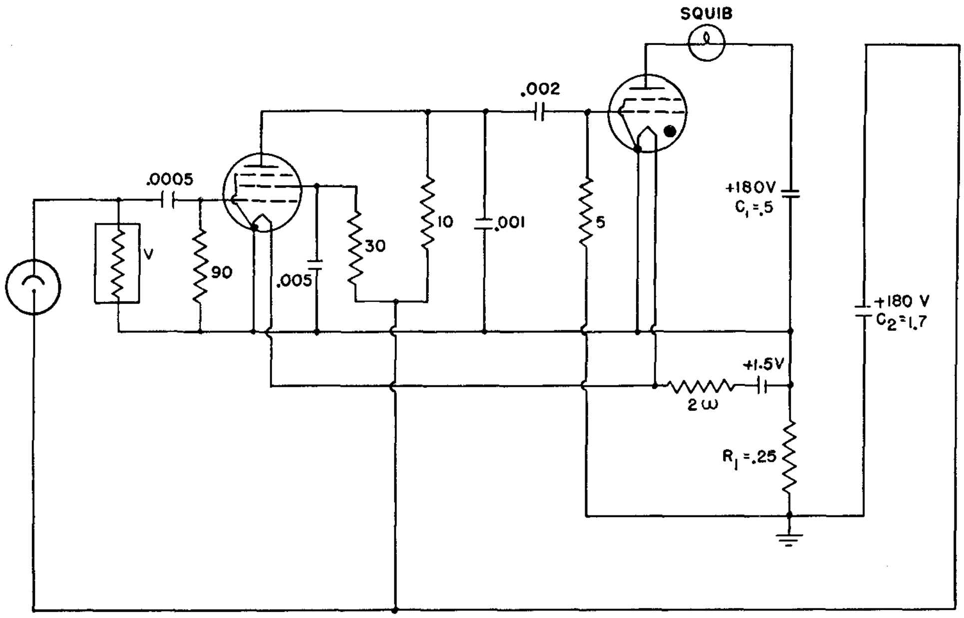


FIGURE 14. Circuit diagram of condenser-powered modification of T–4 fuze. Resistance values (unless followed by ω) are in megohms; capacitance values are microfarads.

powered fuze, the National Carbon Company developed a reserve A battery. Only 6 of the condenser fuzes used in the field tests were equipped with these reserve A batteries, and all 6 functioned properly. This indicated that full voltage was developed before arming and that no transients occurred of sufficient size to fire the fuze prematurely. This reserve battery consisted of a zinc outer electrode, cylindrical in form, a similarly shaped, carbonized steel interelectrode, a glass ampoule containing the electrolyte (in this case, chromic acid and sulphuric acid), and a lead weight supported by a shear wire for breaking the capsule during setback.

The advantage of the reserve battery [13,72] over a regular A battery is its indefinitely long shelf life. When a condenser-powered fuze employs it for an A supply, the entire unit has an indefinitely long shelf life. Its disadvantage is the possibility that the ampoule in the battery will be broken by rough handling.

Heater Cathode Tubes. As it is characteristic of heater-type cathodes to continue to emit for some time after the heater voltage is turned off, it is possible to construct condenser-driven units employing heater cathode tubes [15] that would contain no A supply whatever. The cathodes could be heated by an external power source before firing and during flight would stay hot enough to maintain the tube transconductance. Pentodes of this type that were built for PE fuze operation were found to retain their mutual conductance for longer than 10 sec after the heater voltage was turned off,[15] and this would satisfy most antiaircraft fuze requirements. Since these tubes required heating in excess of 5 seconds for proper operation, it would be necessary to heat the cathode continuously during all times of possible emergency use. This would necessitate a long life on the part of the tubes and operation at temperatures low enough not to damage the remainder of the fuze.

To realize the full advantages of the heater cathode pentodes, the development of heater cathode thyratrons is indicated. Also it would avoid complications in the external power supply mechanism if both the pentode and thyratron cathodes could be heated by the same power source which supplies the voltage for the condensers.

Photothyratrons.[56] For the purpose of eliminating the need of an A voltage supply, a thyratron was developed which had a photosensitive surface instead of a filament as a source of electrons. This thyratron was essentially a gas photocell with a grid mounted between the anode and cathode. The development of these tubes did not proceed very far, but some of them seemed quite promising. The critical grid voltage was a function of the plate voltage, the

[redacted]

grid leak resistance, and the light level on the cathode, but in some tubes it had very little dependence on light level. Emission from the grid was a disadvantage in some tubes.

The use of these thyratrons in zero stage fuzes [51,52] (no amplifier) or fuzes which employ amplifier tubes with photoemissive surfaces as cathodes would eliminate the need for an A supply, either internal or external.

5.4.4 Non-Sunfiring and Non-Sunblinding Fuzes

The normal T–4 fuze would fire prematurely if, after arming, the field of view were made to include the sun or to view the sky at a small sun angle [24] (see Chapter 8). The sun angle was defined as the angular difference between the direction from the fuze, of the sun, and of the center of the field of view nearest the sun. This premature firing was believed due to the rapid varying of the sun angle by the yawing of the projectile in flight, and laboratory experiments with units on yaw machines supported this belief.

Even if the sun in the field of view would not fire the fuze, it would cause such a large current in the photocell that any change due to a target that did not obscure the sun would be too small by comparison to trigger the fuze. This phenomenon is called sunblinding.

Photographic records were made of the voltage transients set up in the fuze by yawing the units through the sun on a yaw machine. They revealed that the general form of the signal across the load resistor as a function of sun angle, $dv/d\theta$, was as shown in Figure 15.

The slow change of voltage with respect to angle at sun angles greater than 3 degrees was caused by the bright region of the sky near the sun. The steep sides at about 3 or 4 degrees were due to the sun's emergence into or disappearance from the field of view. The top was flat, for the photocell was too conductive to impede the flow of current when the sun was in the field of view. The small spike at the top was caused by an unexplained discontinuity in the voltage-current characteristic of the photocell.

The T–4 fuze would fire on the sudden application of an obscuration signal if the time rate of voltage change across the photocell load resistance, dv/dt, exceeded the critical value for a sufficient time interval.[31] For signals due to the sun,

$$\frac{dv}{dt} = \frac{dv}{d\theta}\frac{d\theta}{dt}.$$

At sun angles greater than 3 degrees, this quantity may be of firing magnitude provided $d\theta/dt$ is large. The magnitude of $d\theta/dt$ depends, of course,

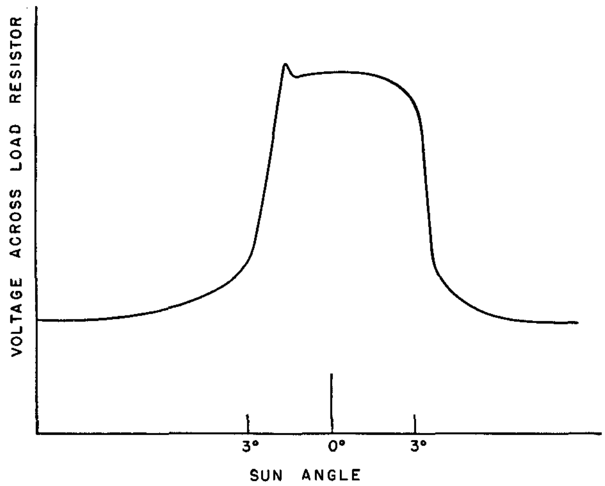


FIGURE 15. Voltage signal developed across photocell load resistor as function of sun angle (angle between sun and center of field of view).

on the angular velocity of the projectile. At sun angles at which the sun enters and leaves the field of view, $dv/d\theta$ is so large that $d\theta/dt$ can hardly be made so small that dv/dt can be reduced below the critical value.

The characteristics of the photocell load resistor are such that if i is the photocurrent and k is a constant, then $dv = k(di/idt)$ and firing may be said to occur when $k/i(di/d\theta)(d\theta/dt)$ exceeds a critical value.

Double Photocell Circuits. The only known PE circuit which gave promise of preventing sunblinding as well as sunfiring was one that employed two photocells [44,48,49] and two fields of view [26] so separated that the sun could not be in both at the same time. This would be quite an important factor in plane-to-plane firing for, as the trajectory does not change much during flight, there is a high probability that a unit which required protection against sunfiring before reaching the target would also require protection against sunblinding upon reaching it.

Two general arrangements of input circuits employing two photocells were considered. One is shown in Figure 16.

As either photocell receives a signal on passing a target, the voltage signal developed across its varistor is reduced by a factor of approximately two by the other photocell-varistor combination. As the sunlight is received by either cell and renders its impedance very low, the impedance of the series

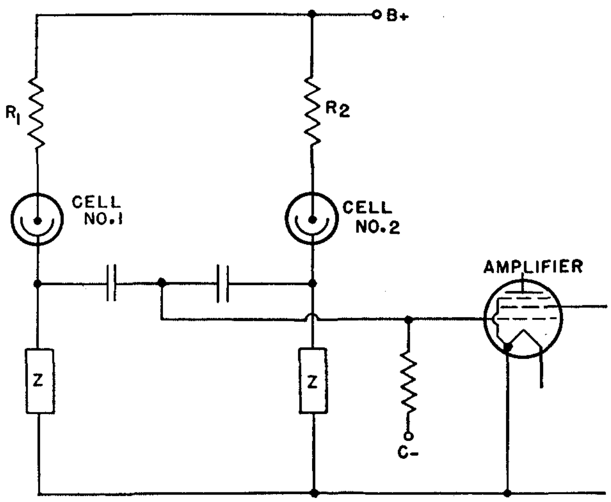


FIGURE 16. Circuit for anti-sunblinding photoelectric fuze using two photocells and two lenses. Elements in rectangles are nonlinear resistances.

varistor is maintained high by the current-limiting action of the series resistor. It appeared that sunfiring could be prevented by the series resistor.[31] If it could be made to limit the current through the photocell to values for which the quantity $di/d\theta$ is low, the sun signals would not contain high-frequency components sufficient to operate the amplifier.

In order that the fuze be sensitive to target signals and not sunfiring, it is necessary that the series resistor be low enough to permit the cell to control the current when the sun angle is large ($di/d\theta$ small) and yet high enough to limit the current when the sun angle is small ($dv/d\theta$ large). As the illumination of the sky varies quite widely from time to time, it seems impossible that a single value of resistance would meet both of these requirements.[37] The photocurrent produced as a cell views any portion of a bright sky may be greater than that produced at another time as the cell views a dark sky and the sun is actually entering the field of view.

The second arrangement of the two photocells is shown in Figure 17.

If the photoemission in each cell is about the same under normal sky illumination, the unit cannot be sunblinded. If either cell receives the direct sunlight, it is effectively short-circuited, and the behavior of the unit will then be almost exactly the same as that of the normal T-4 fuze with the other cell controlling the current. If the current through a photocell is less than its photoemission will permit, its electrical impedance is extremely low because of the nature of its voltage-current characteristic.

If, because of change in the fuze's trajectory, the sunlight is received by the cell which is normally the more conductive, its impedance, already extremely low, is merely rendered somewhat lower, and no significant change in the current occurs.

As the sunlight is received by the cell which is normally less conductive, the current through that cell increases to the amount that the other cell is capable of passing under its normal illumination. A voltage change is thereby produced across the load resistor. Experiments have shown that, since the photoemission in each cell is normally very nearly

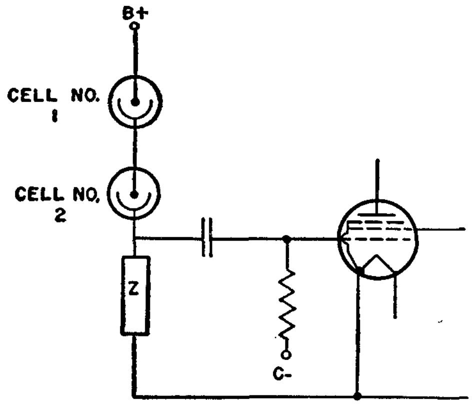


FIGURE 17. Alternate circuit for anti-sunblinding photoelectric fuze.

the same and the fields of view are widely separated, the voltage change will not fire the unit as it is yawed through the sun. But, if one cell has a photoemission that is normally only 90 per cent as great as the other, or less, and is carried in and out of the sunlight at high angular velocities, sunfiring will generally occur. This is because the current change with angle in this case is quite large and is sharply discontinuous as the limiting action occurs. The general form of the yaw signal (voltage versus time) is then that of a sine wave with the peaks cut off sharply on one side. An amplifier with the passband of the T–4 fuze has a high gain for a signal of this form. Its large-amplitude low-frequency components may be adequately attenuated, but its sharp discontinuities produce voltage transients in the amplifier which are as fast as those expected to be received from the target and to trigger the fuze.

Reduction of the sharpness of such discontinuities in the yaw signals may be accomplished by several methods, all of which serve to decrease the quantity $di/id\theta$ or the sharpness with which it changes. The photocells may be selected in pairs to have nearly equal photoemission. The fields of view may be separated quite widely and may be made wide for small percentage widths. High resistances, either linear or nonlinear, may be placed across the less conductive cell. All of these methods were found to have some degree of effectiveness, but the problems had not been completely resolved before work was terminated.

One modification of this circuit which was found to give good protection under most conditions of yaw was that of replacing one of the photocells with a parallel combination of a much less conductive photocell and a 3- to 5-megohm resistor. Normally, the other photocell controls the current, but as it receives the sun, its current is limited by the parallel combination without becoming very large or sharply discontinuous at any time. Protection against sunfiring is lost only if the sky illumination is so great that the single cell does not normally control the current or so low that the current-limiting action of the parallel combination is inadequate. Under most levels of illumination, the protection seemed adequate under most conditions of yaw.

It seems likely that the ideal type of cell to use in series arrangement for prevention of sunfiring would be one whose dynamic impedance is proportional to the voltage across it and inversely proportional to the illumination upon it. Then, as the less conductive cell was carried in and out of the direct sunlight, the manner in which the other cell would assume and release control of the photocurrent would be such as to reduce the sharpness of the discontinuities to a minimum. A possible approximation to this ideal cell is one which has a large space charge effect throughout the operating range. No experiments were done with a cell of this sort.

The type of signals received from targets may be modified so that discrimination in their favor can be more easily accomplished in the circuit. Restriction to small widths of the field of view for large percentage widths would make sharper the signals received from the target. This does not necessarily conflict with the previous suggestion of making the field of view wide for small percentage widths.

Circuit with Modified Input. One simple modification of the T–4 input circuit was tested and found to be proof against sunfiring.[37] It had no sensitivity at light levels greater than 1.5 lumens, so that its use would have been restricted to low light level applications, such as ground approach firing. The circuit modification [31,37] is shown in Figure 18. It

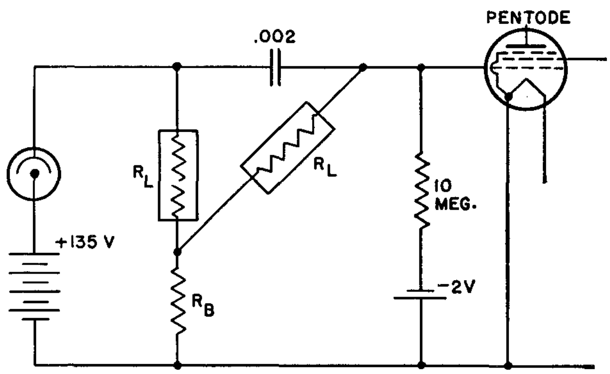


FIGURE 18. Modification of input circuit of T–4 fuze to prevent sunfiring. Elements in rectangles are nonlinear resistors.

comprised the standard MC–380 circuit components with the addition of a linear resistor and a nonlinear resistor, and having the input coupling condenser reduced from 0.005 to 0.002 microfarad. The linear resistor, R_0, in series with the photocell, must be adjusted to values between 0.5 megohm to 2.0 megohms, depending on the photocell sensitivity.

The three main factors that contributed to making this modification proof against sunfiring were:

1. The negative mismatch of the load resistance to the cell reduced the variation of voltage with photocell current across the load resistance at high light levels.

2. The grid-to-ground impedance was rapidly reduced as the photocell current rose.

3. As the voltage across R_B was increased, voltage was applied in increasingly larger proportions to the grid of the amplifier due to the action of the nonlinear coupling resistor. The operating point of the tube was shifted to regions of extremely low gain by the high positive bias.

Twenty-five of the modified fuzes were tested for sunfiring properties on the yaw machine and found satisfactory. Equally good results were found in field tests (see Chapter 8).

5.4.5 Zero Stage Fuzes

In the interest of simplicity, attempts were made to develop a satisfactory zero stage fuze, that is, a circuit employing no stage of amplification.[51,52] The magnitude of the photocurrents employed in the T–4 fuze was such that, at all light levels except the very lowest, an obscuration signal of 10 per cent was capable of firing an amplifier, provided the dynamic load impedance was sufficiently high. This impedance consisted of the parallel combination of the thyratron grid leak resistor and the photocell load resistor.

A number of zero stage units were built in which a 20-megohm resistor was employed as a photocell load resistance, a 20-megohm thyratron grid leak resistor was used, and a condenser charged to 315 volts was employed as the B supply. A high B voltage was necessary because of the high voltage drop developed across the 20-megohm load resistor at the higher photocurrents. Dispersion of available rockets prevented proper field evaluation of this circuit. This is, of course, significant since the fuzes were intended for use on rockets, and, if the complete round were not brought close enough to the target for function, the weapon would be of no value.

In other experimental units, a second photocell which viewed the sky at a slightly different angle was used as a load impedance. When the photoemission from each cell was approximately the same, each cell served as a high dynamic impedance load on the other. Under these conditions, the unit was more sensitive than the single-cell zero stage unit, the sensitivity was fairly independent of light level, and the unit, unlike the T–4, was as capable of responding to a bright target as to a dark one. Its chief difficulty was that of making the photoemissions of the two cells near enough to the same value. Because of the nature of the photocell voltage-current characteristic, the range of photocurrents that a photocell can pass with a given photoemission, while maintaining a high dynamic impedance, is quite restricted.

If, instead of vacuum photocells, gas-filled photocells are used, the problem of making the photoemission in each cell nearly the same is no longer very serious. The sensitivity for the balanced condition is less than that obtained with vacuum cells, but experiments indicated that such units with thresholds of 1 to 3 per cent were feasible.

5.4.6 Active-Type PE Fuzes

Preliminary calculations and experiments were made on the possibility of operating an active-type PE fuze.[39,40] They indicated that a very sensitive PE fuze should operate at night by the light reflected by a target at distances up to 50 ft if the target is illuminated by a searchlight beam or a light of about 100 candlepower carried by the missile. In either case, the fuze would have to operate on extremely weak light signals.

The most promising type of amplification for a fuze of this type seemed to be that of the electron photomultiplier tube. It would respond to extremely weak light signals and would not be subject to as many sources of noise as is a conventional amplifier. No models of active-type fuzes were built.

5.5 PHOTOCELLS

5.5.1 General

Since the photoelectric cell is the nucleus of a PE fuze, considerable effort was spent in developing a satisfactory cell for fuze use. High sensitivity, ruggedness, and resistance to microphonics were prime requirements. A secondary requirement was the color characteristic. Peak sensitivity in the blue was desired in order to reduce contrast between the sky and clouds.[1,3]

After numerous interim models, a "cartridge" type of high-vacuum photocell was designed (see Figure 19). It consists of a cylindrical glass tube to which are sealed the anode and cathode "headers." This photocell has the following advantages: (1) it is simpler to make; (2) it eliminates the mechanical vibration problem; (3) the elements of the cell are able to withstand greater force due to acceleration; (4) the whole cathode is illuminated, reducing variation in sensitivity due to rotation of the fuze. Although the photosensitive surface is not normal to the incident light, it has been shown that the current produced by a given light flux does not vary appreciably with the angle of incidence, provided the surface is sufficiently "rough."

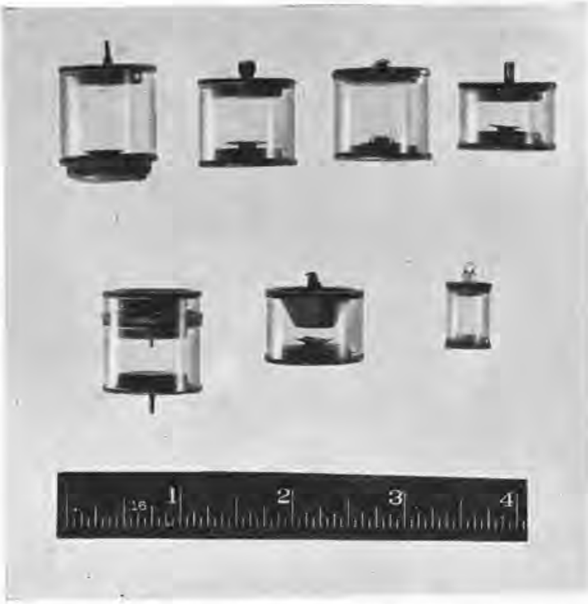


FIGURE 19. Cartridge-type photocells. View at upper left is 1P24 photocell in which cathode (top end) was integral with header. Others, except view in lower left, are experimental modifications to obtain smaller cell for more compact fuze. In lower left is photothyratron.

5.5.2 Sensitivity and Spectral Response

Typical spectral response curves for three types of photosensitive surfaces are shown in Figure 20. The greater sensitivity of a cesium-antimony or S4 surface indicates the desirability of its selection. In addition, although the light received by the photo-

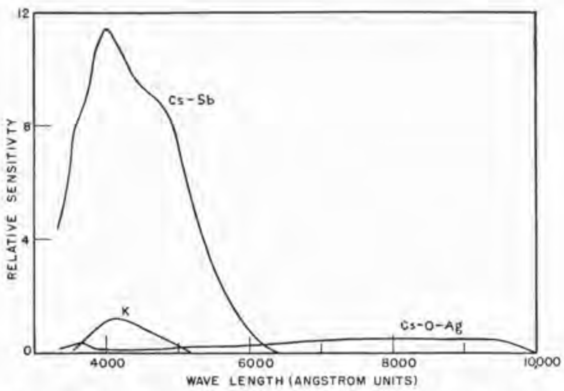


FIGURE 20. Spectral response curves of three typical photosensitive surfaces.

cell in this application contains all wavelengths in the visible spectrum, light received at altitudes above 5,000 ft is predominantly blue.[1] Thus the use of the cesium-antimony surface results in larger currents. Also there is less change in photocell current when the background changes from sky to clouds.[1] With the Cs-O-Ag surface, sensitive in the red, the sky appears dark; transition from clouds to sky causes a decrease in the current, similar to that caused by the appearance of a target plane and results in premature functioning.

In early cells using the Cs-O-Ag surface, it was necessary to use gas amplification to obtain sufficient currents with which to work. Difficulty was encountered with "electrical noise," especially at low light levels. It was in some way connected with the charge accumulation on the glass envelope of the tube, and better performance was obtained by improving the electron optics of the assembly. However, the electrical noise problem was very troublesome until the cesium-antimony surface was adopted.

The advantages of photocells with this type of surface are: (1) greater sensitivity; (2) reduced noise, since gas amplification is unnecessary; (3) low electrical leakage; and (4) reduced contrast between clouds and sky.

The first cells made with the cesium-antimony surface were similar in construction to the first models, which had conical cathodes. They were followed by the more practical RCA–936 cartridge type of photocell with a flat cathode surface. A similar photocell, the GL–516, which had essentially the same electrical and mechanical properties, was developed by the General Electric Company.

Improved technique in depositing the photosensitive surface,[103,105] principally the removal of the cesium capsule from the photocell proper to a tubular extension which was later sealed off, resulted in the development of the 1P24 (GL–564), which was approximately twice as sensitive[33] as any of the preceding types. [The GL–564 experimental photocell became the 1P24 according to Radio Manufacturers Association (RMA) nomenclature.]

5.5.3 Construction[83]

The photocell consists of a cylindrical lime glass bulb to which are sealed assemblies mounted on headers of Allegheny metal. In preparing the bottom assembly, a nichrome cathode disk is welded to the header, which has been stamped from Allegheny 55. After this assembly has been thoroughly cleaned to remove grease and surface impurities, the glass bulb and the tubulation are sealed to it. A layer of antimony is then deposited on the cathode disk in an extremely good vacuum.

The top assembly consists of a similar Allegheny header to which is welded a nickel cup (see Figure 19). A cesium pellet is placed in the cup and held there by a cover spot welded around the edge of the cup. This assembly is then sealed to the glass bulb. The tubulation is sealed to an exhaust system, and, after a preliminary bakeout at 275 F, the cesium pellet is flashed, depositing cesium on the antimony surface. Excess cesium is removed by further bakeout, and the tube is sealed off.

An attempt was made to simplify construction by depositing the photosensitive surface directly on the Allegheny header. Cells of this type were less satisfactory, possibly because of the difference in base metals, and it was decided to direct efforts toward improvements in the other design.

Further research by the General Electric Company resulted in the development of a procedure for making cells nearly twice as sensitive as those of the preceding design.

Instead of placing the cesium pellet in the nickel cup inside the photocell, it is placed in tubulation sealed to the *anode* header. After bakeout and flashing, the tubulation is sealed off beyond the location of the pellet. The cesium is then distilled into the photocell, where it strikes the cathode disk. Finally, the tubulation is sealed off hot as close to the anode header as possible.

5.5.4 Detailed Properties

1. *Sensitivity.* With 135 volts applied between anode and cathode, and light (color temperature 2870 K) applied to the cathode, the response was required to be not less than 40 microamperes per lumen.[83] (The sensitivity of the 1P24 cells averaged 75 microamperes per lumen.)

It was found that the sensitivity remained remarkably constant under various conditions of storage and exposure.

2. *Gas content (gas ratio).* When potentials of 250 volts and 135 volts were applied between anode and cathode and light was incident on the cathode, it was required that ratio of currents at the two voltages not exceed 1.1.[91]

3. *Cathode uniformity.* With only a 90-degree sector of the cathode illuminated, it was required that as the cell was rotated, the ratio of the maximum to the minimum currents should not exceed 1.5.[94]

4. *Leakage.* With no light incident upon the cathode and 250 volts applied between cathode and anode through a 0.5-megohm resistor, it was required that the current should not exceed 0.005 microampere.[83]

5. *Mechanical uniformity.* The photocells were required to meet fairly rigid mechanical tolerances. For example, the plane of the cathode and the plane of the exterior seating shoulder were required to be parallel within 1 degree.[93]

5.5.5 Special Cells

1. *Gas-filled photocells.* A number of photocells of the RCA–936 type were made with gas introduced to provide amplification. The average sensitivity of 27 cells tested at an anode voltage of 135 volts was 149 microamperes per lumen. However, when the manufacture of a very high sensitivity surface was accomplished (1P24), the need for a gas-filled photocell disappeared, and the research program was terminated.

2. *Special thyratrons.* The development of a photothyratron [56] was undertaken in an attempt to replace the small gas-filled thyratron with a tube requiring no filament power. Since the fuze already incorporated an optical system, the use of a photocathode for the thyratron suggested itself. A number of tubes which were made indicated that a thyratron could be developed to function when a reasonable quantity of light fell on the cathode. These tubes, designated as the RCA C–7071, were essentially gas-filled photocells of the cartridge type with a grid mounted between the anode and the cathode surfaces (see Figure 19). Although the good photothyratrons were capable of passing the large currents required, they presented three major disadvantages: (1) the critical grid firing voltage was dependent on the cathode illumination; (2) it was difficult to prevent photoemission from the grid; (3) large currents, if repeated many times, damaged the cathode surface. Therefore, attention was turned toward the development of a cold-cathode tube. Electrical characteristics of these tubes are given in reference 109.

Several cold-cathode thyratrons (R–6236) were designed and made, taking advantage of the rigid cartridge photocell construction. The tubes developed were more sensitive and better constructed than preceding tubes of the cold-cathode type, but they operated on a positive grid voltage of about 70 volts, making them less desirable than the filament-powered thyratrons used in the T–4 fuze.

3. *Small photocells.* Two sizes of small photocells were constructed in an effort to make the fuze more compact (see Figure 19). One size was $\frac{1}{2}$ in. in diameter and $\frac{21}{32}$ in. in length, while the smaller was $\frac{3}{8}$ in. in diameter and $\frac{15}{32}$ in. in length. All cells had high sensitivities and appeared to be satisfactory. Average values are given as follows:

	Sensitivity (μa per lumen)	Uniformity (per cent)	Gas ratio
Larger cells	102.7	87.9	1.03
Smaller cells	93.0	74.3	1.04

Chapter 6

LABORATORY METHODS FOR TESTING T-4 FUZES AND COMPONENTS[a]

6.1 INTRODUCTION

THE PRIMARY AIM of the laboratory tests of fuzes is to predict their operation when fired on missiles, in order to insure reliable performance. Because of the wide variation in operating conditions, limits for the test must necessarily cover extreme ranges. Although simulation of field operations is a primary aim, ease of performing any given test is also of great importance. The most important overall test for predicting field operation is the sensitivity test. Other general tests are as follows: arming, noise, critical bias, vibration, jolt, temperature and humidity, and mechanical. Furthermore, specific tests have been performed on photocells, lenses, nonlinear resistors, and pentode tubes.

6.2 SENSITIVITY TESTS

6.2.1 Dropping Ball Method [1]

The first type of sensitivity test which compares with field operations is one in which a falling ball simulates the target, passing the field of view of the lens. In the actual test, the distance between the fuze and path of the ball was chosen so that the falling ball would have the velocity required to give a pulse of the right duration to correspond to the missile's passing the target. Black balls of increasing size were dropped until the thyratron fired, as indicated by a neon bulb connected to the thyratron. This process was repeated until the fuze fired on a ball of given size 5 successive times but not on the ball of next smaller size. Sensitivity was calculated in terms of percentage of total light obscured by the ball. The test was usually performed out of doors in order to provide uniform light intensity of proper magnitude on the photocell.

The falling ball method of determining sensitivity was at best a slow and tedious process, and faster methods were sought.

6.2.2 Mechanical Chopping [2]

The next modification of the sensitivity test involved the use of two lamps, one behind the other, with a chopping bar between them. The apparatus consisted essentially of: two lamps, one for the signal and the other to produce the required light level; a system of lenses; and a high-speed cam-operated shutter to produce a sharp cutoff of the light from the signal lamp. A schematic diagram of the setup is shown in Figure 1.

The signal was varied by using combinations of

[a] This chapter was written by P. J. Franklin of the Ordnance Development Division of the National Bureau of Standards.

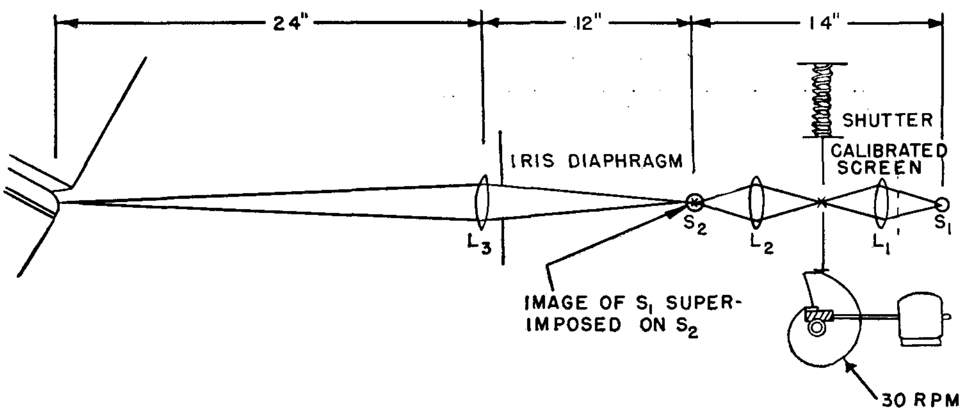


FIGURE 1. Schematic method of measuring PE fuze sensitivity by light chopping. Lens of fuze, on which light is focused by lens L_3, is shown at left. Light source S_2 provides background illumination, and source S_1 (focused on S_2) provides fractional light level which is momentarily cut off by cam-operated shutter.

five wire screens with different meshes. The screens were calibrated with a blue-sensitive vacuum cell (RCA-7052) mounted in a regular fuze assembly. Transmissions, measured with various combinations of screens, checked reasonably well with the values computed from the individually measured transmissions. A table of per cent signal for various screen combinations was then prepared from the various transmissions. If T is the screen transmission; i, the value of the photocell current from lamp S_2; and i_s, the value of the current from lamp S, with no screen; then the signal, S, expressed as a fraction of the initial light level before the signal light cuts off, is

$$S = \frac{Ti_s}{1 + Ti_s} \simeq \frac{Ti_s}{i} \qquad (1)$$

for small signals. Reasonably good agreement was obtained by the method with computed sensitivities based on the photocell characteristic.

A few important points in the design and use of the apparatus should be mentioned.

1. Either the per cent signal adjustment or the light level adjustment, but not both, may be made by means of an iris diaphragm. If a diaphragm is used for one adjustment, then the other must be made by alternating the beam over its whole cross section. Otherwise, the light level and per cent signal will not be adjustable independently of one another.

2. The shutter mechanism must be isolated mechanically from the optical system to avoid serious microphonic effects from the lamp filaments.

3. The effective angle subtended by lenses L_3 at the lens of the unit under test must be smaller than the angular width of the field of the latter lens.

4. A very steady source of direct current, such as a storage battery, must be used for lamp filaments.

5. The shutter must have a rough blackened surface to prevent reflection effects from the lamp S_2. This is important for small signals.

6. The effect from bouncing of the shutter must be eliminated by allowing ample motion after cutoff, or providing a friction catch. A half-inch extra motion after cutoff was found to be sufficient.

6.2.3 Modulated Lamp Apparatus [23]

Although pulse tests for sensitivity were the most reliable method for obtaining design data, they were too time-consuming for production or quality control purposes. A rapid and reasonably reliable sensitivity test used a light source which was modulated with a known percentage of 60-c alternating current. The amount of modulation was increased until the thyratron of the fuze was triggered.

The lamp and fuze were mounted as shown in Figure 2. A set of screens was used for varying the

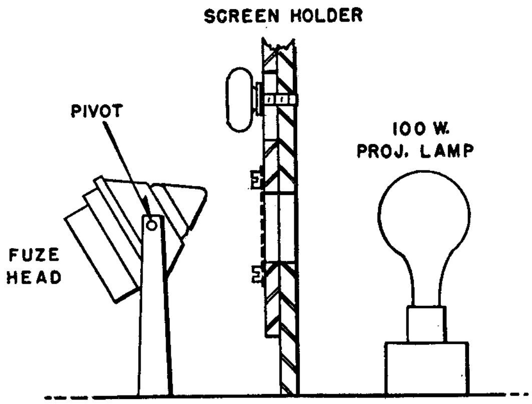


FIGURE 2. Schematic arrangement for measuring sensitivity of PE fuzes with modulated source (lamp). Overall light level is controlled by screens between fuze and source.

light level in steps. The per cent light signal was controlled by the a-c modulation of the lamp and was independent of the level seen by the fuze. For the particular lamp used, the per cent light modulation was approximately ⅕ the per cent voltage modulation. When the lamp was operated at its normal voltage, it aged rather rapidly, and, for a given voltage modulation, the per cent light signal might increase markedly after a few hours. This effect of decreasing thermal inertia of the lamp accounted in one instance for errors up to 25 per cent in threshold (inverse sensitivity) measurements. The diagram of the lamp circuit is shown in Figure 3.

To calibrate the modulating source, a standard fuze head containing a photocell and lens assembly was mounted so that it viewed the source at an angle of 22.5 degrees (see Figure 4). A pair of shielded leads connected the photocell to an attenuator box containing a battery, connections for a microammeter to read photocurrent, and a calibrated, noninductive, continuously variable resistance. The output from this circuit was connected by a shielded cable to one input of a high-gain amplifier. A standard 60-c signal, ordinarily 1 volt (rms), was applied to another input of the same amplifier.

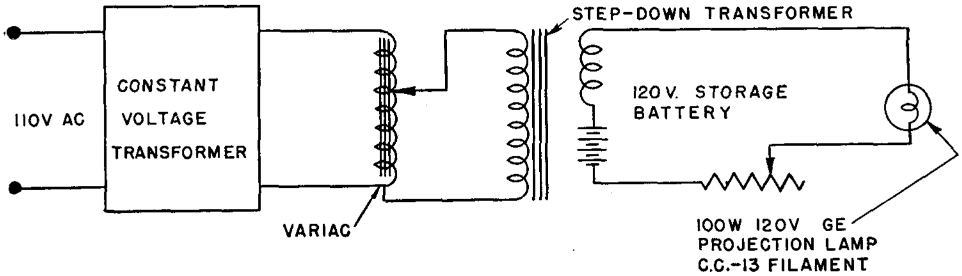


FIGURE 3. Circuit for controlling percentage light modulation of lamp shown in Figure 2.

Inside the amplifier there was provided a calibrated 10,000-ohm step attenuator for the standard signal. The attenuator was ordinarily used at 1/10,000, giving a 0.1-millivolt standard input to the amplifier. The input impedance of the amplifier was 5 megohms, which was high enough so that there was no observable loading effect of the amplifier on either the standard source or the photocell circuit. This precaution was important.

The actual calibrating procedure follows: The standard source was set at 1 volt (rms). With the input selector on Number 2 (Figure 4) and the input attenuator at 1/10,000, the gain control was adjusted until the oscilloscope showed a conveniently readable deflection, for example, 10 divisions. The d-c lamp voltage was then set at the proper point (see following paragraph on light level calibration), and the Variac (Figure 3) was set at some arbitrary reading at which it was desired to calibrate. This was more convenient than using an a-c voltmeter to read the modulation and was proper, provided the line voltage was controlled. The gain control was left fixed, and, with the input selector on Number 1 (Figure 4), the photocell series resistance was varied until the oscilloscope reading had returned to the value at which it was set. The input to the amplifier was then 0.1 millivolt (rms), and the photocurrent ripple was, therefore, $10^{-4}/R$, where R was the resistance in the photocell circuit. If I is the current reading of the microammeter, then the "fractional"

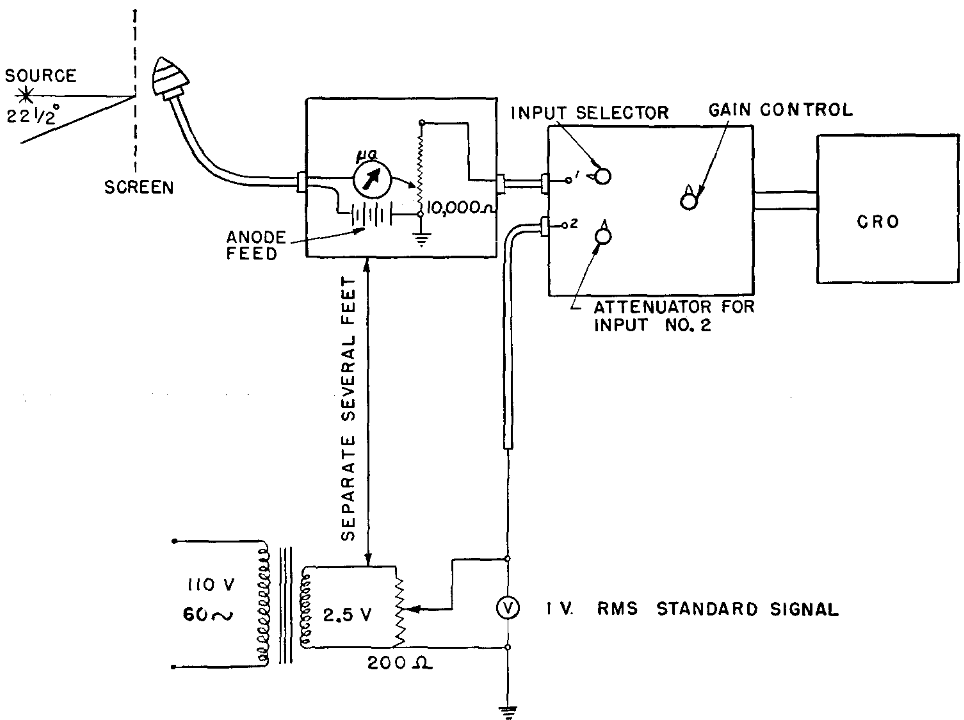


FIGURE 4. Schematic setup for calibrating modulated light source (Figure 2) used for measuring sensitivity of PE fuzes.

[redacted]

light signal is $10^{-4}/RI$ (rms). The peak per cent signal is then by definition equal to $100\sqrt{2}$ times this value. A typical calibration curve is shown in Figure 5.

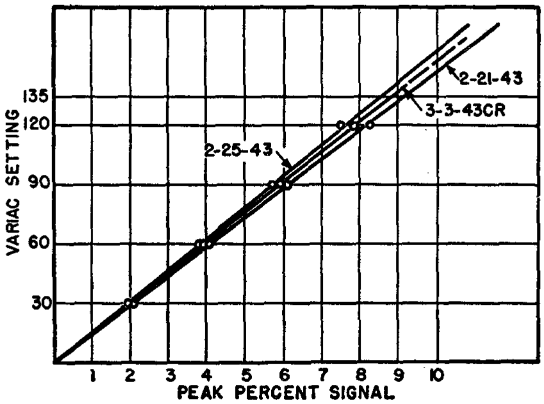


FIGURE 5. Calibration of modulated lamp in terms of Variac setting (Figure 3).

Threshold measurements had to be carried out over a range of light levels which covered approximately the expected range of operation of the unit. As light conditions and photocell sensitivities varied widely, it was necessary to define a reference light level in terms of some kind of standard source.[20,21]

Preliminary to this, a set of standard heads (cell and lens in regular fuze noses) were made up with cells having sensitivities in the neighborhood of 25 to 30 microamperes per lumen.[23] These were used for light measurements under various conditions to determine the range of values likely to be encountered. Variations of light level with time of day and altitude are discussed in Chapter 4.

For tentative standardization, a representative light level, L_0, was defined as the level which would produce a current of 8 microamperes in a representative standard cell-lens assembly containing a cell with a sensitivity of 30 microamperes per lumen. The levels at which thresholds were to be measured were $0.05L_0$ (below which the unit rapidly became insensitive), L_0, and $3L_0$. The last level was high enough to allow for fairly extreme conditions of high light level, including a probable increase in cell sensitivity, as manufacturing technique improved.

Originally the light level L_0 was defined in terms of photocell current. Since photocell sensitivities changed gradually with time, the level L_0 was later defined in terms of photometric standards by the Bureau of Standards Photometry Section. The standard light level L_0 could be suitably defined as that level for which the light flux from a standard lamp at the surface of the lens was 0.75 lumen per sq cm and in such a direction that the photocurrent in the cell was a maximum.

The *threshold* of a fuze was defined as the peak percentage modulation of the light signal required to trigger the thyratron. This depended on the form and duration (or frequency) of the signal, and, with the modulated light apparatus, referred to a 120-c sinusoidal signal. The *peak per cent modulation* referred to the maximum departure from the mean light level, expressed as a percentage of the mean level. Thus, in the case of the sinusoidal signal, the peak signal denoted one-half the peak-to-peak value rather than the total fluctuation.

6.3 OPERATING TESTS

The operating tests on the MC-380 assembly consisted of measuring: (1) threshold (by the modulated lamp method), (2) stability at arming, (3) electrical noise, and (4) self-destruction [SD] time. These tests were made in a single test position, using a test circuit as is shown in Figure 6. The terminals of the MC-380 adapter are as indicated in Figure 5 of Chapter 5.

The MC-380 nose was powered by voltages from large-capacity batteries in the test circuit rather than from a fuze battery. However, provision was made to use, for special tests, a fuze battery (lower right, Figure 6). The switches marked S were ganged together and when closed, put the test equipment in operating condition. The switches marked S1 were also ganged, and, when these were closed, power was supplied to the fuze circuit, initiating the arming cycling. The clock was also started to measure SD time. The switches S2 had to lie in position of the arrows in order for the SD circuit to be effective. SD was always measured first in order to obviate the possibility of erroneous values being obtained from residual voltages or the capacitors in the SD circuit.

Voltage was applied to the thyratron plate by a 0.1-microfarad capacitor charged through a 0.5-megohm resistor from the B supply. When the thyratron was triggered, the condenser discharged through the thyratron in series with a 10-ohm resistor (simulating the resistance of the electric detonator). Firing was indicated by the lighting of

[redacted]

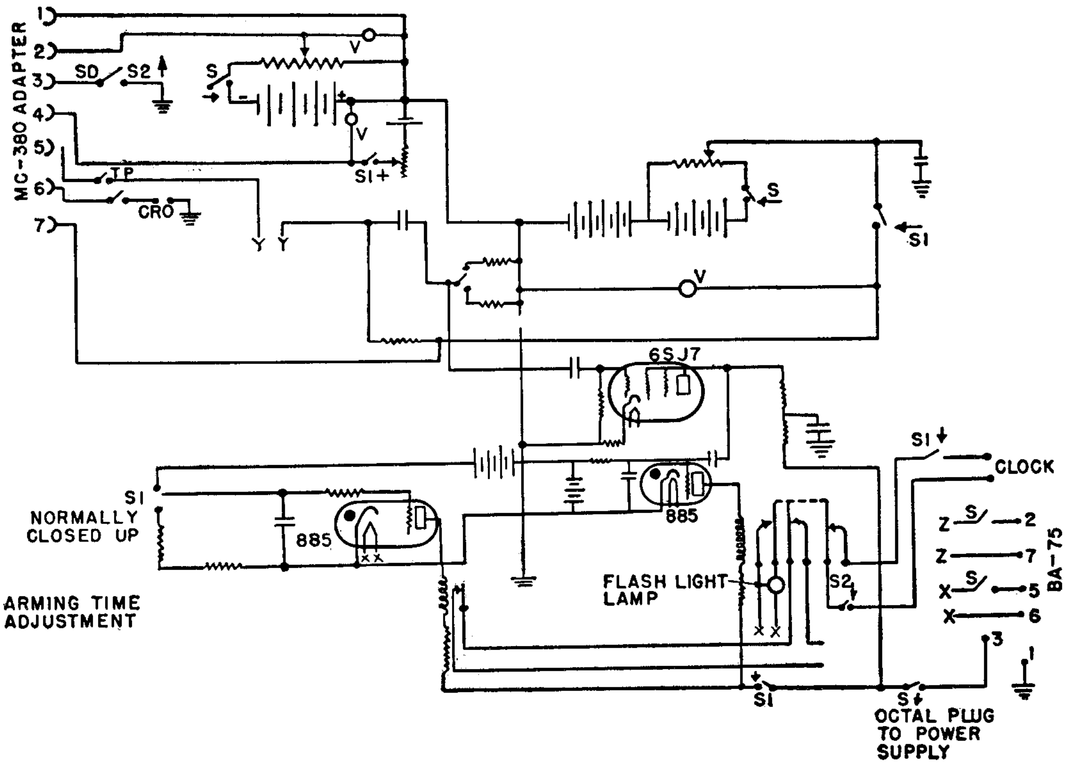


FIGURE 6. Circuit diagram of operating test position for T-4 fuzes. With fuze nose (MC-380) plugged into terminals (upper left), measurements were made of threshold, noise, stability at arming, critical bias (of fuze thyratron), and SD time.

a flashlight lamp. This was operated by a relay which was energized by the pulse across the 10-ohm resistor. An inverter stage and auxiliary thyratron in the test circuit coupled the resistor to the relay. A contact on the same relay was available to stop the clock in order to give an automatic measure of SD time. Firing of the thyratron prior to the proper range of SD times indicated a defective unit. After the SD was measured, the S2 switches were shifted to the position away from the arrows, rendering the SD circuit inoperative and disconnecting the clock.

The arming test was accomplished automatically by means of a time delay circuit and another 885 thyratron, which operated a relay and closed the thyratron plate circuit at an adjustable time after closure of filament and plate circuits. Firing of the thyratron at the end of the arming time delay indicated failure of the unit to arm properly.

The noise test was performed by setting the thyratron grid bias at —4 volts (—6 volts was the normal operating value). If the unit fired within a specified time limit (30 sec), it failed the noise test.

The threshold measurements were made by setting the light level at the desired value, resetting the filament plate and bias voltages at the desired values, and turning up the light signal slowly by means of the Variac control (Figures 2 and 3), until the unit fired. The per cent threshold for this light level could then be read from the calibrating curve for the per cent signal against Variac reading (Figure 5).

A critical grid bias test was made to determine the margin of safety between the noise level and the signal required to fire the unit. A motor-driven potentiometer placed across the C bias circuit gradually reduced the bias until the fuze fired. The discharge of the thyratron operated a relay which stopped the motor and permitted a reading of the bias voltage to be taken.[38] The difference between this value and the normal bias gave the holding bias for the fuze.

6.4 SERVICE TESTS

A number of tests were made to determine the ability of the fuze to stand up under various service

[redacted]

conditions. These tests included vibration, jolting, and temperature and humidity cycling. Mechanical gauging tests were also made to insure that the fuze could be installed properly in the rocket.

The vibration test gave an indication of the microphonic stability of the vacuum tubes. It also served to show up defective workmanship, such as poorly soldered connections and insecure anchoring of parts (sometimes due to incomplete potting). A commercial vibrator was used (Vibratron by American Tool and Instrument Co.). The frequency of vibration was selected to correspond to the frequency of maximum gain of the amplifier. The amplitude of vibration was $\frac{1}{64}$ in. An excessive or spurious signal at the thyratron grid (observed on an oscilloscope) led to the rejection of a fuze.

Samples of fuzes from production lots were required to withstand a standard Ordnance Department jolt test. The test was primarily intended to check the safety of the arming mechanism of the fuze, but it also gave an indication of the ability of the fuzes to withstand rough handling.

Temperature cycling tests involved storage at —40 C for 48 hours followed by another 48 hours at +60 C. The electronic assemblies were required to be in operating condition after such exposure. Occasionally, units would fail due to defective potting. The wax potting compound was liable to shrinkage at the low temperatures and sweating at the high temperatures. Careful control of the potting process was necessary to avoid troubles from these causes.

Resistance of the fuze to high humidity was determined by water immersion tests. Units were required to be in operating condition after immersion in water at room temperature for 4 hours.

In addition to gauging of the threads and dimensions, mechanical tests included strength tests on the contact pins of the base of the electronic assembly, and center of gravity measurements. The latter served primarily to show up voids in the potting process.

6.5 PHOTOCELL TESTS

6.5.1 Electrical Tests

The following properties of the photocell were determined by electrical tests: sensitivity, spectral response, uniformity, gas multiplication, and dark current. A noise test, originally planned as a routine test procedure, revealed that only about 0.1 per cent of the first 3,000 cells produced were noisy, and it was discontinued. The electrical tests were all made in a single test setup shown schematically in Figure 7. The control panel is shown in Figure 8, and the wiring of the photocell circuit is shown in Figure 9. Full details of the equipment are in references 30 to 36, inclusive.

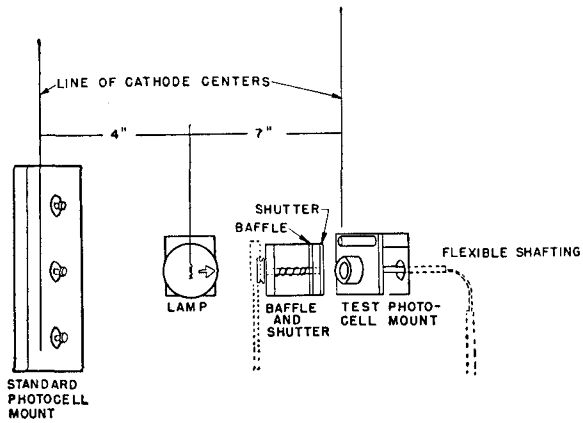


FIGURE 7. Schematic diagram of arrangement for calibrating photocells used in T-4 fuzes.

The light source (lamp, Figure 7) was a 32-candlepower, 6-8 volt, double-contact, bayonet connection, automobile lamp, mounted in a standard lamp socket. A supply of these lamps was calibrated by the Optical Section of the National Bureau of Standards giving: (1) the current at which the lamp had to be operated in order to secure a color temperature 2870 K, and (2) the candlepower of the lamp at this current. Soldered connections to the lamp were necessary to prevent current fluctuations. The energy for the lamp was supplied by an external storage battery.

The mount for the photocell under test was so located that the center of the cathode of the cell was approximately 4 in. from the center of the filament of the lamp. In order to be able to test the uniformity of the photocell in different directions, the photocell mount could be rotated by means of a flexible shaft connected to a knob at the front of the panel (Figure 8).

A baffle screened the entire photocell from direct illumination, except for an elliptical beam which illuminated the cathode; this beam extended just far enough outside the cathode to insure that the cathode was entirely illuminated.

A shutter was provided so that a 90-degree sector

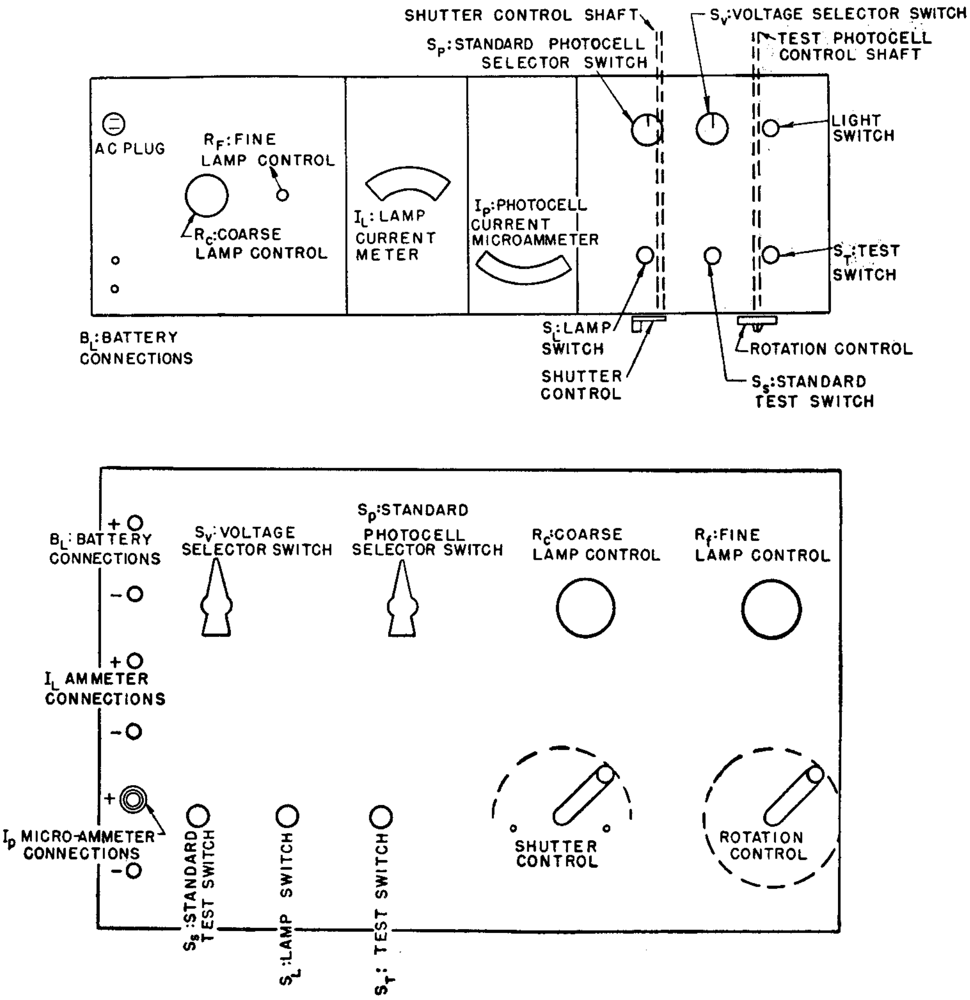


FIGURE 8. Diagram of control panel for apparatus used to calibrate photocells.

of the cathode could be illuminated. The shutter could be placed in or withdrawn from the beam by means of a control lever at the front of the panel.

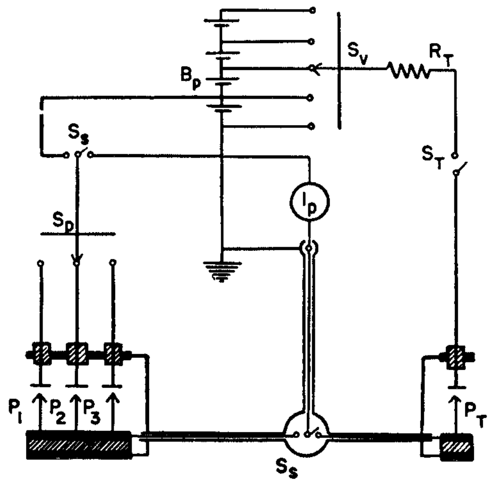
In the design of the photocell circuit, care was taken to insure that no leakage in the circuit itself would be indicated on the microammeter. The elimination of such currents was important in measuring conduction at very low or no illumination. The test cell and the standard cells were so connected in the circuit that any leaks across insulators were shunted to ground without passing through the meter. Shielded cables were used.

In addition to the photocell under test, three standard photocells were mounted in the apparatus for use in adjusting the lamp intensity. When a lamp was installed, it was operated at the specified color temperature as indicated by the ammeter, and the photocurrents flowing in the standard photocells were observed. Thereafter, the lamp was regulated by setting the standard photocell currents. This assured constancy of the light flux from the lamp. Three standard photocells were used to permit a check. A marked disagreement between the lamp current and the standard photocell current indicated a deterioration of the lamp; it was then necessary to replace the lamp. The fact that the photocells used as standards were of the same type as those under test nullified largely any change in lamp characteristics. The standard photocells had voltage applied only when they were actually in use; only 22.5 volts were used on the standard cells. These precautions were intended to prevent deterioration of these photocells. The standard photocells were

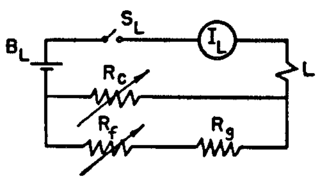
[redacted]

selected for average sensitivity, high uniformity, low gas multiplication, and low dark current.

An accurate measurement was made of the distance from the lamp filament to the center of the rim of the cathode of the photocell in the test cell mount. From the geometry of the setup and the



PHOTOCELL CIRCUIT



LAMP CIRCUIT

FIGURE 9. Wiring diagram of photocell circuits of Figure 7, showing shielding, switches, meters, and batteries. P_1, P_2, and P_3 are reference photocells, and P_T is cell under test.

candlepower of the lamp, the quantity of light illuminating the cathode could be evaluated. The sensitivity of the photocell could thus be determined from the measured photocell current and the calculated quantity of light on the cathode.[15]

All requirements specified for the various tests were to be met after the photocell had been stored in darkness for at least one week (corresponding to probable field service conditions for the fuzes). The test for sensitivity was to be made immediately after the photocell had been removed from dark storage. The light incident upon the tube after removal from darkness and prior to this test was never to exceed an equivalent of 10 footcandles for 1 minute. All remaining tests were to follow the sensitivity test.[29]

The test of sensitivity was repeated with a Corning signal red filter (4.0 ±0.1 mm in thickness) introduced into the light beam. The response with this red filter was not to exceed 10 per cent of the response without a filter.

A sampling procedure was adopted to apply to the cells used for this test. Twenty sample photocells were selected at random from each day's production. If more than one photocell failed the test specified, an additional sample of 80 cells was selected and tested. If more than a total of 5 photocells from both samples failed, the entire day's production was tested, and the photocells failing the test were rejected.[29]

Uniformity Measurement (Sensitivity Distribution). Uniformity was very important in the earlier types of photocells since the lens system focused light from each section of the sky upon a small area of the cell. Lens systems that were developed later (T–4 fuze) focused light from all radial directions over the entire cathode, and nonuniformities of the cathode surface were less important.

In order to measure uniformity, the test for sensitivity was repeated, except that the shutter was brought into the beam; an opaque sector in the beam of light was thus provided so that only a 90-degree sector of the cathode was illuminated. The opaque sector was so oriented that its central radius was perpendicular to the direction of the beam. As the photocell was rotated about its axis through a complete revolution, the maximum and minimum photocurrents were observed. The uniformity was defined quantitatively as the ratio of the minimum to the maximum sensitivity. It was required that the ratio of the maximum to the minimum photocurrents not exceed 1.5.

Gas Multiplication Measurement. Tests over long periods of time showed that a cell might be relatively free from gas for several months and then become too gassy to be used. Any gas leakage at the time of the test seemed to be a sufficient cause for rejection.

In order to measure gas multiplications, the test for sensitivity was repeated with the cathode completely illuminated. The photocell current was observed when the voltage applied between the anode

[redacted]

and the cathode was changed from 135 to 250 volts. The ratio of the currents was specified as not to exceed 1.1.

Dark Current Measurement. The electrical leakage test could not be made satisfactorily during damp weather due to the leakage on the outside of the glass, representing no defect of the photocell itself.[15] If a photocell displayed an unsatisfactorily large leakage, it was not to be discarded until it was clear that this was not due to conductance on the outside of the glass.

For dark current measurements, the lamp was extinguished, and the current was observed when a potential of 250 volts was applied to the anode through a 0.5-megohm resistor. The small current could be detected by noting any motion of the meter needle when the voltage was turned off. The current was not to exceed 0.005 microampere.[29]

6.5.2 Visual Inspection and Mechanical Tests [15]

The photocells were subjected to visual inspection. Loose dirt on the inside and stains on the glass were to be noted. It was important that the bulb be sealed to the headers without excessive wrinkling of the glass, that the glass be free from flaws, and that the headers be accurately placed.

Gauges were constructed in order to check the accuracy of construction in certain respects.[15]

It was required that the angle between the plane of the cathode and the plane of the seating shoulder be checked by mechanical measurement before the photocell was sealed. The planes were specified to be parallel within 1 degree. The same sampling procedure used for testing spectral responses was to apply to this test.

At the seal of the bulb to the cathode header, the glass was not to overhang beyond the edge of the header. No part of the photocell was to extend beyond a distance of 0.458 in. from the axis of symmetry of the cathode header.[29]

The photocell was expected to satisfy all electrical and mechanical requirements after centrifuging. The photocell, mounted in any position, was to be spun in an approved centrifuge. The cell was to be subjected to a force of not less than 2,500g, computed for the midpoint of the photocell. This test was made on a sampling basis.

6.6 LENS TESTS

A good magnifying glass with a magnification factor of about 4 was used to detect flaws in the surface, the slit, and the paint of the lens. A simple light source was used for inspecting the completed lens assembly to determine the position of the photocell and any obstructions in the field of view. A sketch of this apparatus appears in Figure 10. The

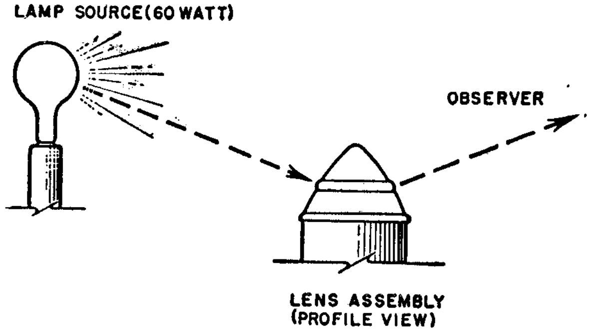


FIGURE 10. Schematic arrangement used to examine lenses in T-4 fuzes.

lamp projected a source of light into the lens at a forward angle of approximately 22.5 degrees. The observer could view the cathode from the equivalent position on the opposite side. The lens and photocell assembly could be rotated through an angle of 360 degrees.

Tests of angular distribution of the field of view of the lens were made with the apparatus shown in Figure 11. The lens assembly, or fuze, was mounted at F. A stick was pivoted about a center, C, at the lens assembly, transcribing an arc, graduated from 0 to 90 degrees. The 0-degree mark, located in a plane perpendicular to the fuze axis, passed through the center of rotation. A lamp S was mounted on the stick, one meter from the lens. A slit in front of the lamp restricted the light beam at the lens to an angle no greater than 0.2 degree in the plane of the arc. The lens could be rotated about the fuze axis with the photocell fixed, and the cell could be rotated with the lens fixed. The photocell was mounted permanently; lenses were removable. The photocell was connected to a 135-volt battery through a microammeter and a series resistance. Another method consisted of using an a-c lamp source and measuring the photocell output with an a-c galvanometer.

Lenses in completed fuzes were tested by apply-

[redacted]

ing 110 volts a-c to the proper terminals on the base plate of the fuze nose through a d-c microammeter or galvanometer with a protective resistance in series. The meter measured the rectified photocurrent.

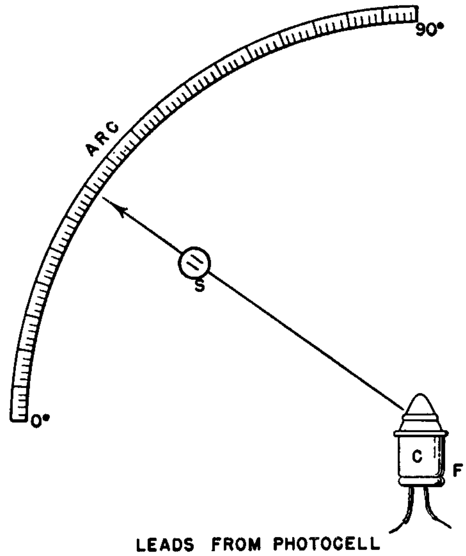


FIGURE 11. Arrangement used to measure field of view of lens-slit system of T–4 fuzes.

The photocurrent was not actually proportional to the light intensity since, during part of the a-c cycle, the photocell was operating below the saturation point on its current-voltage characteristic. However, by comparing the a-c meter readings against d-c, a calibration for the a-c method was obtained. For example, the 50 per cent transmission point with d-c voltage might be at 52 per cent with a-c.

6.7 TESTS ON NONLINEAR RESISTORS

Resistance measurements were made of the critical values (discussed in Section 5.4) of the nonlinear, photocell-load resistors. Ordinary high-resistance measuring circuits were used. In addition, the load resistors were examined for self-noise.

Since the fuze was designed to operate on a change of light level of approximately 1 per cent, the specification for maximum noise level in the load resistor was set at a value equivalent to a 0.1 per cent light signal. The noise level was determined by passing a current of 10 microamperes through the resistor and amplifying the random voltage changes with a properly shaped amplifier. The pulses could then be observed on an oscilloscope, or could be used to trigger a thyratron, which would indicate if the resistor were noisy.

6.8 PENTODE TUBE TESTS

Traces of gas were found to be present in vacuum tubes after long periods of storage. The input impedance of the fuze amplifier was lowered by a large

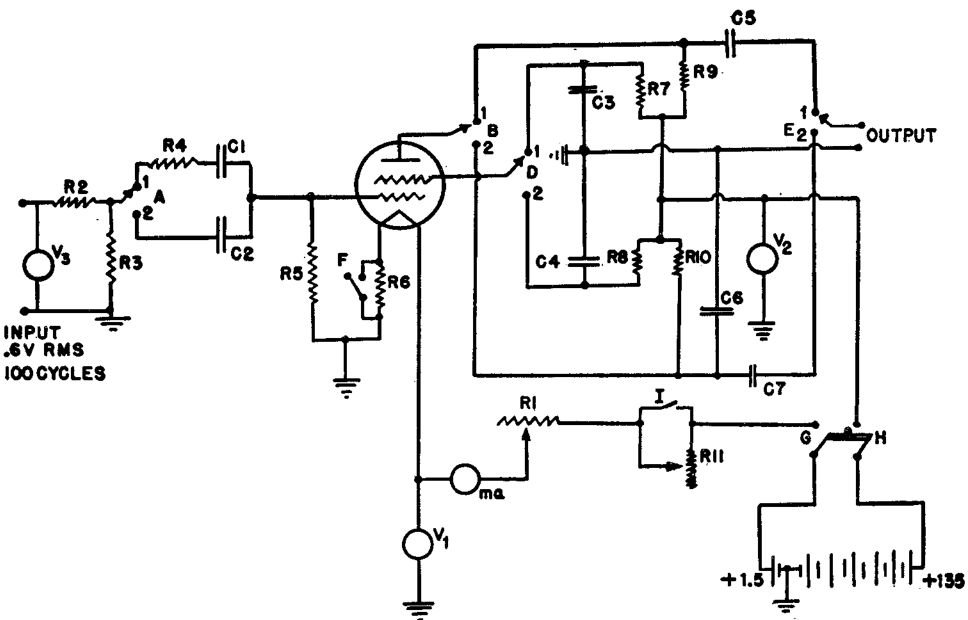


FIGURE 12. Amplifier used to measure input impedance of pentodes for T–4 fuzes.

[redacted]

factor in the presence of such traces of gas.[6] The presence of gas in pentodes after long periods of storage, moreover, set a practical limit on the magnitude of the input impedance of the amplifier.[12,16]

The input impedance of the pentode tubes was measured by means of the test circuit shown in Figure 12. A 10-megohm resistor was connected in series with the input grid. Readings were obtained for the output voltage with and without the 10 megohms shorted.[18] Using a 0.6-volt (rms), 100-c input, the voltage output of the stage was specified to be in the range 1.5 to 7.5 volts (rms) at all times between 2 sec and 30 sec following the application of voltages for the first time.[28] (The definition of "first time" was any time following shipment, subject to the time limit specified, assuming that no voltages had been applied to the tube since the final factory testing process.) These tests were not to be made sooner than 72 hours after the final factory aging process.

Chapter 7

FIELD TEST METHODS FOR PE FUZES[a]

7.1 INTRODUCTION

The types of field tests may be classified as follows:

1. *Performance tests:* to determine the reliability and sensitivity of the fuze under standard conditions.

2. *Effectiveness tests:* to determine damage effectiveness. General considerations for effectiveness tests on proximity fuzes are given in reports on radio fuzes[b] and are applicable to all proximity fuzes. No special techniques have been developed for effectiveness tests with photoelectric fuzes.

3. *Radio reporter tests:* use of special units containing radio transmitters to determine behavior of the fuze, fuze components, or the missile during flight. A more common name would be telemetering.

4. *Miscellaneous:* other tests such as arming distance tests and sunfiring tests. Test procedures on these tests will be discussed as needed in Chapter 8 of this volume, which deals with fuze performance.

The main part of this chapter deals with the performance tests. The principal considerations in planning these tests were:

1. *Provision of adequate safety precautions.* All tests were made with inert-loaded projectiles. The operation of the fuze was indicated by a spotting charge.

2. *Provision of means for quantitative measurements of results.* Visual observations and photographic records were made of the burst positions. Principal reliance was generally placed on readings from the photographic films.

3. *Simulation of combat use.* This involved selection of suitable targets and firing conditions. Firing of rockets from the ground against a stationary target was suitable for simulating combat fire since it gave the same velocity of fuze relative to target as plane-to-plane pursuit fire for planes moving at approximately equal speeds.

7.2 TESTS ON BOMBS[1a]

Four types of field tests (not including reporter tests) were made during the bomb fuze development:

1. *Flyover tests.* Fuzes were mounted on a rack on the ground, and an airplane was flown over them at various heights. These tests were of considerable value in determining fuze sensitivity. They gave no information on fuze reliability since the fuzes were not subject to the vibration or background light variations of a bomb in flight.

2. *Free fall tests.* Fuzes were mounted on bombs and dropped from an airplane. No target was used. This tested reliability but gave no information on sensitivity. The fuzes were detonated by self-destruction before they reached the ground.

3. *Airborne target tests.* Fuzes mounted on bombs were dropped against towed sleeves and against drones. Photographs from the bombing plane, the tow plane, or drone control plane, and from an additional observation plane provided data for determining burst positions.

4. *Ground approach tests.* Some fuzes mounted on bombs were dropped over wooded terrain and a few other types of terrain. The heights of function were estimated visually.

7.3 TESTS ON ROCKETS FIRED FROM A PLANE

The proving ground tests of photoelectric fuzes mounted on rockets may be divided into plane-firing tests and ground-launched tests. In order to facilitate observation of burst positions and trajectories, the rounds fired from airplanes were directed against stationary balloons. The balloons were of black rubber and were sausage-shaped, 5 ft in diameter and 15 ft long (see Figure 1). They were moored at heights of 150 to 500 ft. Rocket dispersion was high, and, in order to improve the probability of the fuze passing within operating distance of a target, several balloons were used simultaneously in some of the tests. Some difficulties were encountered with ground light variations. This problem was eliminated by raising the targets over water instead of land.

[a] This chapter was written by Alex Orden of the Ordnance Development Division of the National Bureau of Standards.
[b] See Division 4, Volume 1.

 [redacted]

FIGURE 1. Target balloon for plane-firing tests.

Observations were made visually and photographically from stations on the ground. The bursts were indicated by smoke puffs. Some of the rockets were provided with smoke tracers to show the trajectory. The rocket launching tubes are shown in Figure 2.

FIGURE 2. Rocket launching tubes on wing of P-40.

7.4 TESTS ON ROCKETS FIRED FROM THE GROUND

There were three kinds of rocket firing from the ground:

1. High-angle firings (30 to 60 degree elevation) against a stationary target.
2. Horizontal firings (0 to 10 degree elevation) against a stationary target.
3. High-angle firings for ground approach function.

In the high-angle firings, the target generally used was a black balloon 12 ft in diameter. It was moored to the ground and tied to a barrage balloon above it. The target balloon and barrage balloon are shown in Figure 3. A cloth panel assembly, which presented a target aspect 9x18 ft, was also used. It was hung from the barrage balloon and also moored to the ground. The launcher was a rail assembly or tube mounted on a swivel base (Figure 4). It was necessary to aim the launcher on each round as the target shifted in the wind. The elevation varied from 30 to 60 degrees and the range from 1,000 to

FIGURE 3. Barrage balloon and 12-ft diameter spherical target balloon for photoelectric rocket fuze tests.

FIGURE 4. Launcher for 3¼-in. practice rockets for photoelectric fuze tests.

2,000 ft. In some of the early tests, the rockets were equipped with tracers to show the flight paths. Fuze functioning was indicated by a smoke puff (Figure 5). The bursts were located relative to the target

FIGURE 5. Smoke puff indicating fuze function against target.

by trigonometric calculations based on photographs and transit measurements from two observation posts. Although function shown in Figure 4 appears to be beyond the target, it is actually slightly ahead of it.

On horizontal ranges, the target was hung between poles at a height of about 75 ft. The targets used were: (1) large targets consisting of many strips of black cloth hung from a fishnet or ropes (Figure 6) (these generally provided a target pulse well above the fuze threshold); (2) small targets consisting of a single black panel assembly, which provided threshold pulses; (3) a series of panels of increasing target aspect, spaced about 100 ft apart along the trajectory.[12,15]

The following is a description of a four-target array set up at Blossom Point Proving Ground. The first target was a black panel, 3x4 ft, on a pole 75 ft to the right of the line of fire. The target was in a vertical plane parallel to the rocket trajectory. It was 75 ft above the ground and was intended to be high enough to obscure sky light from the fuze, i.e., to be above the rocket trajectory. The pole was 900 ft from the rocket launcher. This was about 200 ft beyond the arming point for 0.7-sec arming switches The second target was a similar panel, 4x11 ft on a pole 100 ft farther from the launcher. The third and fourth targets were each horizontal panels hung from ropes between poles. The rockets were intended to pass 30 ft below these targets. The third was 3x5 ft with a short side parallel to the trajectory and was 100 ft beyond target No. 2. The fourth was 3x10 ft and was 100 ft beyond target No. 3.

For average trajectories 75 ft to the left of the first two targets and 30 ft below the last two targets, the peak target obscurations were calculated to be 0.9, 1.8, 3.5, and 7.0 per cent, respectively. The computations were made on the assumption that ground light was 10 per cent as intense as sky light. If the ground light were relatively greater, the obscurations percentages were smaller. In calculating the obscuration of the first two targets, the areas of the supporting poles, which were above the horizon relative to the rocket trajectories, were considered part of the target.

It was necessary that the fuzes pass under the target to receive a sufficient target signal. Attempts to use black targets on the ground were unsuccessful as the light change relative to the surrounding terrain was not sufficient to operate the fuze, except at very close passage.

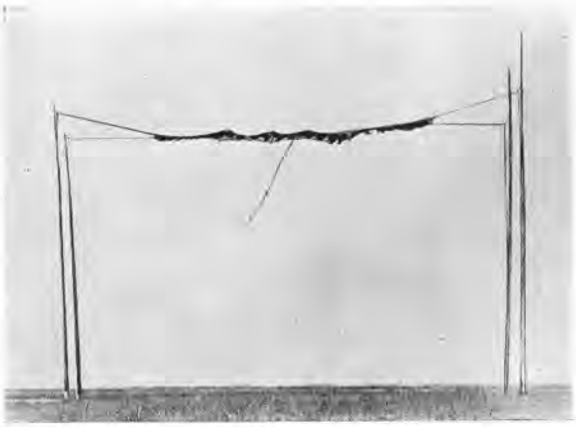


FIGURE 6. Large target consisting of pieces of black cloth attached to 15x75-ft fishnet for photoelectric rocket fuze tests.

The launcher on the horizontal ranges was fixed in position. During the latter part of the development, a special tube launcher 45 ft long was used to reduce rocket dispersion. The terrain between the launcher and the target had to be level and uniform in color in order to avoid pretarget functions due to ground light variations. Visual and photographic observations from the launcher position and from a side station along a line at right angles to the trajectory at the target provided direct measurements of burst position.

The differences and relative merits of *high-angle* and *horizontal* firing ranges were:

1. *Rate of fire.* Testing was much more rapid on the horizontal range due to the fixed mounting of the target and launcher. High-angle targets had to be raised and lowered each day, and the launcher had to be aimed on each round because of drift of the target.

2. *Accuracy of observation.* On horizontal ranges all coordinates of burst position and target passage distance were seen at right angles. Accurate data were obtained by direct measurement of photographic films and were checked by visual observations. In high-angle firing, the observations generally had to be made at oblique angles. Burst positions were obtained by trigonometric calculations based on film measurements and transit data. Gradual motion of the target made it necessary to make surveying measurements on each round. Small errors in these measurements resulted in an appreciable loss of accuracy in burst location determinations. Due to the oblique angle of view, direct visual observations were of little value. (See previous comment in text relative to Figure 5.)

3. *Flight range.* The greater flight range in high-angle fire was an advantage since it provided information on rounds which did not function on the target. On fuzes which had the self-destruction feature, the high-angle range provided a test of the reliability of self-destruction. On the horizontal range, the self-destruction score was of no significance, as late functions might have been due to either ground approach light variations or self-destruction; moreover, flight times overlapped the spread of self-destruction times. On fuzes which were not provided with self-destruction, the long time of flight on high-angle shots provided valuable engineering information concerning rounds which did not function on the target.

4. *Target signal.* The high-angle target was free from disturbance by nearby objects. Target signals on horizontal ranges were sometimes affected by the poles which supported the target or by ground light variations. Some uncertainty in the interpretation of burst position data was thus introduced when horizontal ranges were used.

5. *Launcher.* A long launcher to reduce dispersion could be used in horizontal fire since the launcher and target were fixed. A launcher of equal length would have been too cumbersome for high-angle fire since the launcher had to be aimed on each round. Small dispersion reduced the number of rounds necessary to determine the radius of action against small targets.

6. *Sun effect.* Horizontal ranges, on which the direction of fire was approximately due north, were free of sunfiring effects throughout the day. In high-angle fire, the sun was at a critical angle at some time of day, no matter what direction of fire was used, unless the target or launcher location was changed when the sun angle became critical.

To summarize, horizontal ranges were superior in most respects and ultimately replaced high-angle fire for all development and acceptance tests. However, the spherical balloon used in high-angle firings was ideal for engineering purposes in evaluating fuze sensitivity and was not equaled by the small targets hung from poles. The technique for sensitivity testing with a single small target or series of targets was still under development when the work on photoelectric fuzes was stopped.

Horizontal ranges were used for acceptance tests on production lots.[9] The primary purpose of these tests was to determine whether production samples would meet specified reliability requirements. Large targets were used, and the target signal was ordinarily well above the fuze threshold. The sensitivity of production lots was controlled primarily by laboratory tests.

7.5 RADIO REPORTER TESTS

Radio reporters provided a means for determining behavior of the photoelectric fuze throughout the

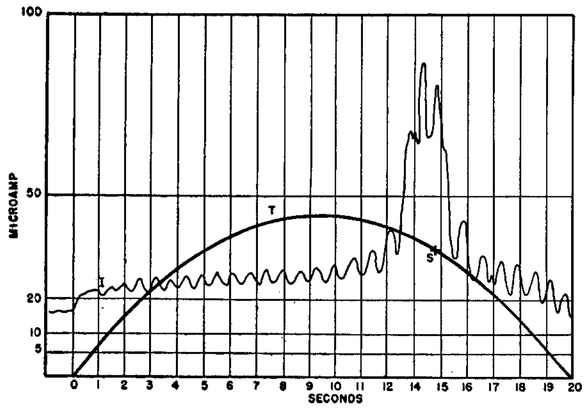


FIGURE 7. Photocell current versus time record obtained by use of radio reporter.

flight of the projectile. The principal use of the reporters was for determination of the magnitude of posed new test ranges.[5-8,10,13,14] Reporters also pro-

[redacted]

posed new test ranges.[5-8,10,13,14] Reporters also provided engineering information on rate of yaw, sun pulses, and microphonics.[11]

A radio reporter consists primarily of a short-wave radio transmitter whose output is modulated by the output of the fuze. A receiver on the ground picks up the signals from the bomb or rocket which carries the fuze, and transfers them to an oscilloscope, where they can be observed visually and recorded photographically for detailed study. Some of the principles employed in the *radiosonde,* a widely used device for transmitting weather information from the upper atmosphere to the ground, were employed in reporter design.[2,3,10]

A reporter record for a rocket fired from the ground is shown in Figure 7. Photocell current is plotted as a function of time. The ripples in the curve were apparently due to rocket yaw and the high peak to the sun. The curve marked T indicates the trajectory of the rocket.

Chapter 8

EVALUATION OF PE FUZES[a]

8.1 SERVICE TESTS ON T-4

THREE SERVICE TESTS were performed on T-4 fuzes. These were tests performed by the Ordnance Department to determine the suitability of the fuzes for specified operational uses. Other tests on PE fuzes reported in this chapter were development tests or routine acceptance tests.

The service tests were: (1) 12 salvos, 5 rounds at 0.1-second interval per salvo, 5-tube stationary launcher, HE-loaded M-8 rockets, Aberdeen, June 23, 1943;[32] (2) 500 rounds, fired singly from a stationary launcher, HE-loaded M-8 rockets, Aberdeen, May 1943;[50,51] (3) 24 rounds, fired singly from a stationary launcher, inert-loaded, 3¼-in. Cenco practice rockets, Fort Bragg, April 14, 15, 1943.[9,26]

These tests were performed in preparation for a proposed use of the M-8 rocket with proximity fuzes as a barrage antipersonnel weapon by the Ground Forces. Tests (1) and (2) were the only tests of T-4 fuzes on HE-loaded rockets.

The Fort Bragg firings (3) were intended to test the ground approach firing characteristics of the T-4 fuze. The rounds were fired over various types of terrain. Twenty-two rounds, fired at angles of elevation of 15 to 30 degrees, functioned properly at heights visually estimated at 2 to 35 ft. Two rounds, fired at an angle of elevation of 65 degrees, functioned near the tops of the trajectories, probably due to the sun.

It should be noted that ground approach operation of the T-4 fuze occurs on a probability basis. An adequate variation in reflected light from the ground has to be seen by the fuze in order for operation to occur. As indicated by the Fort Bragg tests, the probability that such a variation will be seen appears very high. The properties of the fuze as a ground approach weapon were investigated when it became evident that the weapon, because of high dispersion of the M-8 rocket, would not be used in the air-to-air role as originally intended.

The 500 HE-loaded rounds, fired at Aberdeen, were intended primarily as a test of the safety of the fuzes with respect to rearward fragments from early functions, possibility of functions before arming, safety in handling, and any other safety problem that might appear in the firing of a large number of rounds. A few fragments from early functions flew back in the general direction of the launcher. This was not judged a serious safety hazard. There were no early functions before arming; hence the tests were considered to have proved the safety of the fuzes for general use.

The purpose of the 5-round HE salvos at Aberdeen was to determine whether or not sympathetic firing occurred. By sympathetic firing is meant the functioning of one or more fuzes during flight, caused by the effects of functioning of another fuze during flight. There are several ways in which the functioning of one fuze may cause others to function sympathetically. These may be grouped as follows: (1) on *seeing* the smoke, flame or fragments from a preceding HE burst, (2) microphonic disturbances set up either by the striking of the rocket by a fragment from another burst or by sound shock.

The launcher had 5 tubes about 10 ft long, mounted in parallel on a wooden frame with about 10 in. between centers. The firing elevation was 50 degrees. To induce sympathetic action during the useful portion of the flight, one fuze in each salvo was set to fire intentionally at approximately 2.5 sec after ignition.

The rockets in each salvo were fired at intervals of nominally 0.1 sec. On account of variable lag in ignition of the propellant, the interval between take-off of successive rockets was irregular, and in some instances a rocket actually preceded one which it was supposed to follow. Rocket velocities were about 1,000 ft per sec.

The results are shown in Figure 1. The length of the time bars gives a rough measure of the probable error in the time measurements. Figures in parentheses (immediately following the salvo number) give the order of firing of the rocket with the intentional burst fuze. A zero indicates that this round did not burst. Numbers in brackets (at extreme right) give the number of rockets which failed to fire in the salvo. All rounds were expected to burst

[a] This chapter was written by Alex Orden of the Ordnance Development Division of the National Bureau of Standards.

by self-destruction if they were not accidental earlies or sympathetic functions.

On the basis of the results shown in the figure, it appeared that T–4 fuzes on M–8 rockets were quite susceptible to sympathetic functioning. The effect could be reduced by increasing the salvo time interval. However, under normal conditions, without in-

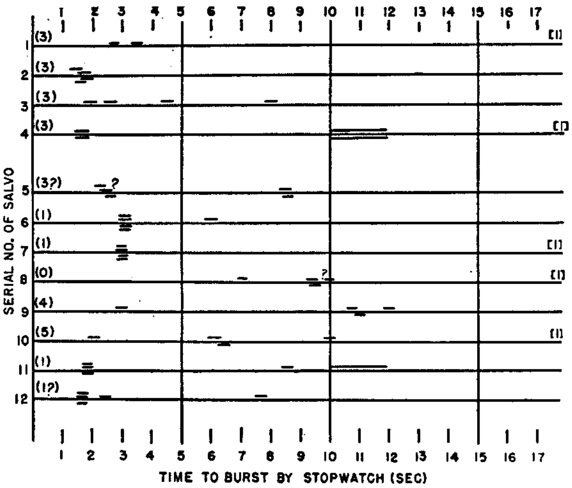


FIGURE 1. Function times on salvos of five T–4 fuzes fired at 0.1-second intervals on M–8 rockets to test for sympathetic functioning.

tentional self-bursts, sympathetic functioning would probably not be a serious problem as the percentage of accidental early functions of T–4 fuzes was generally low. Sympathetic bursts caused by functions on a target would probably detract little from the effectiveness of the fuze.

8.2 T–4 FUZES FIRED FROM A FIGHTER AIRPLANE

One hundred and seventy-six T–4 fuzes were fired from a U. S. Army P–40 fighter plane. These tests were conducted at Aberdeen Proving Ground, September 29, 1942, through January 24, 1943. The fighter plane had 3 launcher tubes mounted in a cluster under each wing, permitting 6 rounds to be carried per mission (see Figure 2, Chapter 7). The projectiles were fired singly. The fuzes were T–4 experimental pilot production samples.

The target range was over the Chesapeake Bay at Mulberry Point. The projectiles were fired southward at target balloons tethered above the bay. The target was at first tethered from the shore, but in view of the high percentage of boundary functions caused by shoreline irregularities it was moved out over the bay.[b]

The target consisted of 1 to 4 sausage-shaped, black balloons (Figure 1, Chapter 7), or a 12-ft spherical balloon (Figure 3, Chapter 7). The targets were tethered over the bay at altitudes of 150 to 500 ft.

Difficulties in the firing technique caused erratic results in the first 8 rounds fired. These are excluded in the following overall summary:

Function on target	54
Early function	9
Function beyond target or self-destruction	39
No function	66
Total	168 rounds

The above figures give a gross score for the fuzes of $54/168 = 32$ per cent. The gross score of 32 per cent functions on target represents the performance of the fuze-rocket combination. No reliability score for the fuzes alone can be given since reasonably accurate trajectory data are available for only a small percentage of the rounds fired. The available trajectory data plus visual observations indicated that, within a radius of 50 to 75 ft from the target, the fuze was highly reliable. The large number of nonfunctions apparently represent rounds on which the flights were too short for self-destruction. The fuzes generally did not burst on approach to water, an expected result because of the uniform reflection from the water's surface.

Figure 2 shows the distribution of function time of the rounds that functioned on the target. The mean time was 1.6 sec. Assuming a rocket velocity relative to the plane of 800 ft per sec and a plane velocity of 340 ft per sec (230 mph), the average firing range was consequently about 1,800 ft.

8.3 ACCEPTANCE TESTS OF MC-380 FUZES

Acceptance tests were made on production lots of PE fuzes produced by four manufacturers. The tests were conducted at Fort Fisher Proving Ground, North Carolina; Blossom Point Proving Ground, Maryland; and Aberdeen Proving Ground, Maryland.

The Fort Fisher Proving Ground N range was laid out so that the projectile flight was over uni-

[b] Random functioning of the fuzes due to ground light variation was a difficulty expected in testing. At the higher altitudes anticipated in operational use, random ground light variations would have a negligible effect.

[redacted]

form brownish-green marsh grass. The launcher and fish-net target are described in Chapter 7. The target rested in a horizontal plane at 75 to 85 ft above the ground, with its long dimension normal to the trajectory of the projectile and its center 1,000 ft from the breech of the projector.

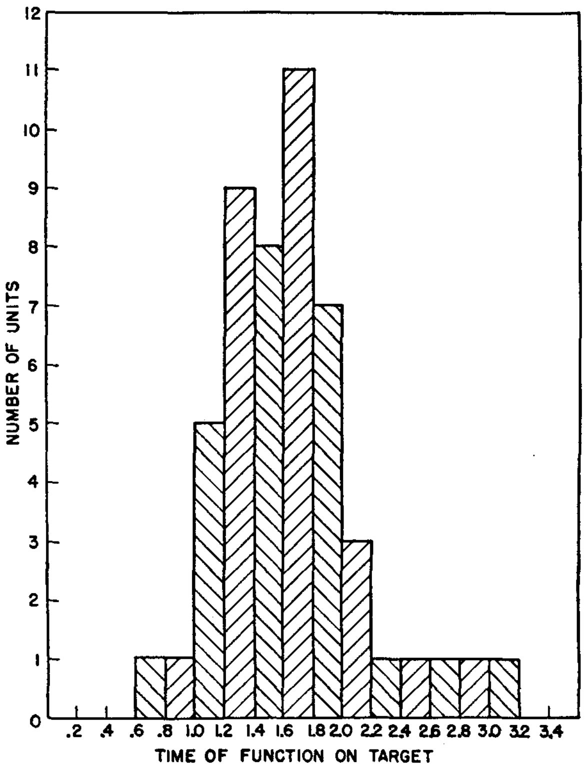


FIGURE 2. Times of function on target of T–4 fuzes on M–8 rockets fired from P–40 airplane at Aberdeen Proving Ground.

The PE target range at Blossom Point Proving Ground was quite similar. Projectors were, at first, a 12-ft seamless steel tube, and, later, a 45-ft tube, made up in three sections. The range was 1,240 ft for the 12-ft tube and 1,100 ft for the 45-ft tube. The target was supported 95 to 105 ft above the ground and consisted of a fish net, 15x75 ft in size, to which were attached pieces of black cloth, 3 ft square. The whole target was fireproofed.

The PE range at Aberdeen Proving Ground was located at C Field. The firing was done from a 40-ft seamless steel tube of 4⅝ in. inside diameter, located on a tower approximately 60 ft in height. The tower was located very close to the water's edge. The target was located 1,000 ft from the tower and supported by four poles placed in the water. The trajectory was over water, except for the first few feet. Therefore, firing was done over a uniform surface up to the target. The target consisted of screen wire 10x65 ft, which supported dark painted canvas at 70 ft above the water level.

The projectile used for acceptance firing of the fuzes was the Army M–9 practice 4.5-in. rocket.

The fuze assembly consisted of the T–4 fuze nose, a BA–55 battery and a SW–200 (0.4-sec or 0.7-sec) switch, assembled and inserted in an M–381 booster housing (see Figure 2, Chapter 3). The components MC–380, BA–55, and SW–200 were checked on the Army Field Test Set IE–28 for safety and proper operation before final assembly. The booster housing contained a black powder wafer spotting element to indicate the functioning of the fuze.

The acceptance test was normally performed on a sample of 20 units from each production lot of 1,000 fuzes. All samples were selected at random from the lot after the fuzes in the lot had successfully passed all other requirements of the specification. In all cases the projectile was aimed to pass under the target. The region of sensitivity for the target was generally defined as the region beneath the target, at least 30 ft above the ground and between the poles supporting the target.

Normally a production lot of 1,000 fuzes was accepted when 10 fuzes out of the sample of 20 had functioned within the region of sensitivity of the target. If more than 10 of the 20 samples failed to function properly, further tests were conducted, as specified by the contracting officer.

Table 1 is a summary of the acceptance tests on fuzes produced by each manufacturer. Only fuzes passing within the region of sensitivity are included in the scoring.

8.4 SMALL-TARGET TESTS WITH T–4

8.4.1 Introduction

Target tests with the T–4 fuze may be divided into two classes: (1) small targets, which tested the sensitivity of the fuze as well as its reliability, and (2) large targets, which provided pulses well above the threshold, and hence served only as a test of fuze reliability. Early tests on preproduction samples of the T–4 fuze at Fort Fisher against a 12-ft diameter balloon were *small-target* tests. Later the technique of testing against a large target (hung from poles) was developed for acceptance testing. Reliability

[redacted]

TABLE 1. A. Acceptance test results: Westinghouse Electric and Manufacturing Co.

Lot numbers	No. counted in score	On target *	Early *	Late or self-destruction *	Nonfunction *
1–128	1,446	1,281 (88.6%)	87 (6%)	14 (1%)	64 (4.4%)
1–10	153	142 (92.8%)	3 (2%)	0	8 (5.2%)
11–20	121	116 (95.9%)	3 (2.4%)	0	2 (1.7%)
21–30	109	101 (92.7%)	5 (4.6%)	0	3 (2.7%)
31–40	148	139 (93.9%)	5 (3.4%)	1 (0.7%)	3 (2%)
41–50	105	95 (90.5%)	4 (3.8%)	0	6 (5.7%)
51–60	100	92 (92%)	3 (3%)	0	5 (5%)
61–70	100	83 (83%)	11 (11%)	0	6 (6%)
71–80	130	104 (80%)	17 (13%)	0	9 (7%)
81–90	100	84 (84%)	12 (12%)	1 (1%)	3 (3%)
91–100	100	82 (82%)	12 (12%)	1 (1%)	5 (5%)
101–110	100	88 (88%)	4 (4%)	3 (3%)	5 (5%)
111–120	100	91 (91%)	3 (3%)	3 (3%)	3 (3%)
121–128	80	64 (80%)	5 (6.25%)	5 (6.25%)	6 (7.5%)

* Figures in parentheses indicate percentages of the total.

TABLE 1. B. Acceptance test results: Western Electric Co.

Lots	No. counted in score	On target *	Early *	Late or self-destruction *	Nonfunction *
1–103	1,063	967 (91%)	35 (3.3%)	15 (1.4%)	46 (4.3%)
1–10	120	109 (90.8%)	7 (5.8%)	2 (1.7%)	2 (1.7%)
11–20	113	100 (88.5%)	10 (8.8%)	0	3 (2.7%)
21–30	100	92 (92%)	1 (1%)	0	7 (7%)
31–40	100	91 (91%)	2 (2%)	0	7 (7%)
41–50	100	91 (91%)	3 (3%)	0	6 (6%)
51–60	100	94 (94%)	2 (2%)	0	4 (4%)
61–70	100	93 (93%)	1 (1%)	3 (3%)	3 (3%)
71–80	100	90 (90%)	1 (1%)	6 (6%)	3 (3%)
81–90	100	90 (90%)	1 (1%)	2 (2%)	7 (7%)
91–103	130	117 (90%)	7 (5.4%)	2 (1.5%)	4 (3.1%)

* Figures in parentheses indicate percentages of the total.

[redacted]

TABLE 1. C. Acceptance test results: Philco Corporation.

Lots	No. counted in score	On target *	Early *	Late or self-destruction *	Nonfunction *
1–62	640	580 (90.6%)	24 (3.7%)	1 (0.2%)	35 (5.5%)
1–10	121	103 (85.1%)	14 (11.6%)	0	4 (3.3%)
11–20	99	96 (97%)	0	0	3 (3%)
21–30	100	87 (87%)	4 (4%)	0	9 (9%)
31–40	100	96 (96%)	2 (2%)	0	2 (2%)
41–50	100	89 (89%)	2 (2%)	0	9 (9%)
51–62	120	109 (90.8%)	2 (1.7%)	1 (0.8%)	8 (6.7%)

* Figures in parentheses indicate percentages of the total.

TABLE 1. D. Acceptance test results: Wurlitzer Co.

Lots	No. counted in score	On target *	Early *	Late or self-destruction *	Nonfunction *
1–99	1,043	935 (89.6%)	58 (5.6%)	8 (0.8%)	42 (4%)
1–10	143	127 (88.8%)	9 (6.3%)	2 (1.4%)	5 (3.5%)
11–20	107	100 (93.5%)	5 (4.7%)	0	2 (1.8%)
21–30	114	107 (93.9%)	6 (5.2%)	1 (0.9%)	0
31–40	108	99 (91.7%)	7 (6.5%)	1 (0.9%)	1 (0.9%)
41–50	100	90 (90%)	8 (8%)	0	2 (2%)
51–60	100	89 (89%)	6 (6%)	0	5 (5%)
61–70	106	89 (84%)	6 (5.7%)	1 (0.9%)	10 (9.4%)
71–80	100	90 (90%)	4 (4%)	1 (1%)	5 (5%)
81–90	100	92 (92%)	5 (5%)	1 (1%)	2 (2%)
91–99	90	76 (84.5%)	3 (3.3%)	1 (1.1%)	10 (11.1%)

* Figures in parentheses indicate percentages of the total.

tests against a large target were adequate for the occasional experimental tests required as well as for acceptance tests. Late in the production program, attention was directed toward circuit revisions and relaxation of component specifications (see Section 8.6 of this chapter). In order to test the sensitivity of fuzes built to less rigid specifications, the large targets hung from poles were replaced by small panel targets as described in Chapter 7 of this volume.

This section presents the results of tests against small targets in order to summarize the available field-test information on fuze sensitivity. The following data are available: (1) About 300 rounds of preproduction T-4 fuzes were fired against the 12-ft diameter balloon at the Laboratory Range at Fort

[redacted]

Fisher. (2) About 250 T–4 fuzes (some standard units, some with modified circuits, and some with components outside specifications) were tested on the North Range at Fort Fisher against a triplanar black panel assembly. Each of the three intersecting planes of the target was 4x4 ft. The target was hung from a rope between the two front poles on the range.[13] (3) About 200 T–4 fuzes (standard and with modifications) were fired at Blossom Point against a four-target array which gave a series of pulses of increasing magnitude (see Section 7.4). (4) During the acceptance tests against a large target, analysis of burst positions demonstrated that a large number of fuzes were triggered by front poles, used to suspend the targets, before seeing the intended target. Calculations showed that the pulse from the poles was of proper size to provide a marginal test of fuze sensitivity.[29]

The rounds fired from a plane against sausage balloons (Section 8.2) were small-target tests, but the data obtained on burst positions and passage distances were too inaccurate to use as a measure of the radius of action [ROA].

8.4.2 Preproduction Tests at Fort Fisher

The test conditions in high-angle firing on the Laboratory Range at Fort Fisher have been described in Chapter 7. The results of the firings against the 12-ft diameter balloon are shown in Figure 3. In the construction of the diagram, the distances of passage on the rounds fired were arranged in the order of increasing distance of passage from the target and counted off in successive groups of 20 rounds. The figure shows the distribution among target functions, late random functions (functions beyond the target and too early for self-destruction), self-destruction functions, and nonfunctions in each of the groups of 20. There were 41 early functions. The distances of passage from the target of the early functions were not included in the counts for Figure 3.

The figure shows that the percentage of functions on target remained constant, within expected statistical fluctuations, up to a radius of passage of approximately 60 ft. With increasing passage distance,

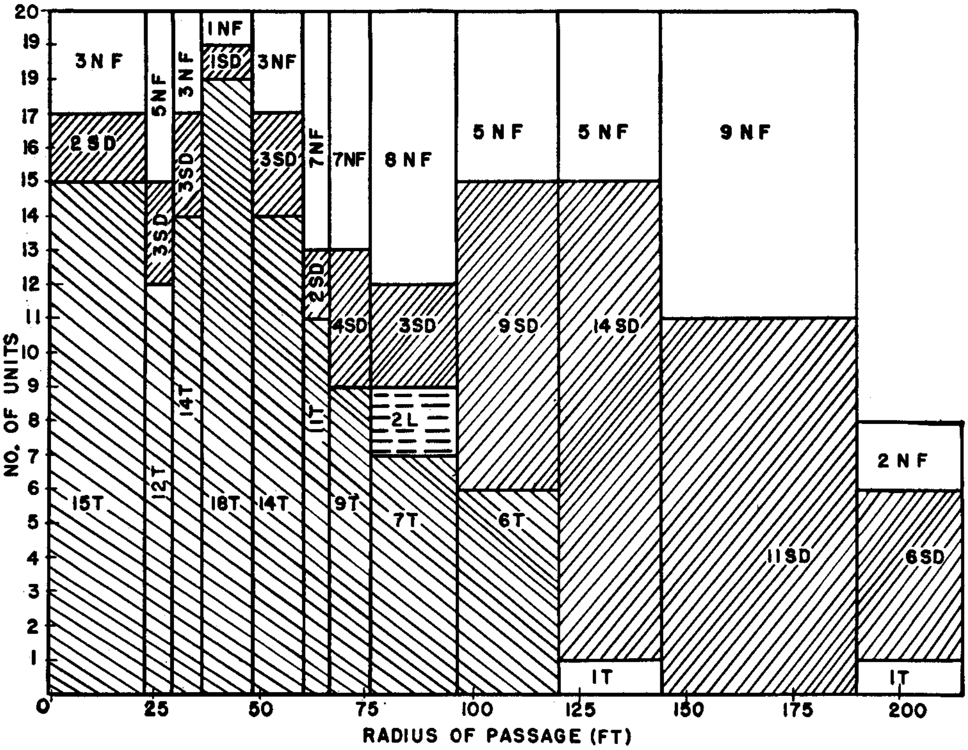


FIGURE 3. Distribution of type of operation with passage distance. T–4 fuzes on 3¼-in. practice rockets fired against 12-ft diameter black balloon. T = target function; SD = self-destruction; L = late function; NF = no function.

[redacted]

the percentage of functions on targets then decreased, while the percentage of self-destruction functions increased.

8.4.3 Tests against Small Target Hung from Poles on the North Range at Fort Fisher

Tests were made against the triplanar 4x4-ft target on the North Range at Fort Fisher to obtain a field check of sensitivity on fuzes modified in various minor ways. The fuze changes and effects on performance are reported in Section 8.6 of this chapter. This section deals only with the radius of action against the small target.

The majority of the various modifications of the T-4 fuzes had shown characteristics practically identical with the standard units in laboratory tests and, likewise, gave about equal field performance. However, several of the modified types showed sensitivity somewhat inferior to the standard model. The results are summarized in Table 2. The rounds not accounted for as functions on poles, on the target, late or by self-destruction were earlies, rocket-motor failures, or duds. Pole functions are considered proper functions. They represent rounds more sensitive than average.

Except for the third line of the table, the percentage of rounds which passed the target and functioned later is too small to obtain a measure of the radius of action against the 4x4-ft target. The results merely show that for the standard fuze and for the modified fuze (whose performance was approximately the same as the standard model, lines 2, 4, 5 of the table), the fuze provided high target scores up to a radius of passage of at least 35 ft. The number of functions on poles was greater on the standard model (lines 1 and 5) than on the modified models which gave equally good performance (lines 2 and 4); hence the standard model was apparently a little more sensitive.

The lower sensitivity of the group with substandard pentodes had been expected on the basis of laboratory characteristics. A study was made of round by round correlation of laboratory sensitivity data with field results for this group. (The laboratory methods of measuring sensitivity are described in Chapter 6.)

Since the laboratory threshold was measured with a continuous alternating signal and the light pulse in the field was a single pulse, the frequency response of the fuze must be taken into account in correlating the laboratory and field results. Direct correlation is expected for groups of fuzes with the same frequency response. The fuzes with substandard pentodes consisted of groups with pentodes made by three manufacturers: Sylvania, Raytheon, and Hytron. Those with Raytheon and Hytron pentodes

TABLE 2. Sensitivity against 4x4-ft target.

Date of test	Type	No. fired	Per cent proper (on target or poles)	No. functioned on poles	No. functioned on target	Target passage distance of function on target (ft)	No. of late functions and self-destruction	Target passage distances of late functions and self-destruction (ft)
May 30, 1943	Standard model	30	83	6	19	24–35	2	27–33
May 30, 1943	New high sensitivity photocells and reduced input resistor (2 to 10 meg)	62	87	2	52	22–32	4	27–36
May 30, 1943	Substandard pentodes and increased amplifier output circuit resistors	59	64	1	37	20–30	18	25–38
June 10, 1943	RPEB-2 (see Section 8.6)	48	83	0	40	28–40	0	...
June 17, 1943	Standard model with photocells outside specifications	39	87	15	19	15–37	1	27

had the average frequency response for T-4 fuzes and hence may be considered together in relating laboratory to field results. Those with Sylvania pentodes are considered separately since they had amplifiers which were peaked at a frequency of about 200 instead of the standard at about 100 c.

The correlation between laboratory and field results is shown in Figure 4. The radius of action of a

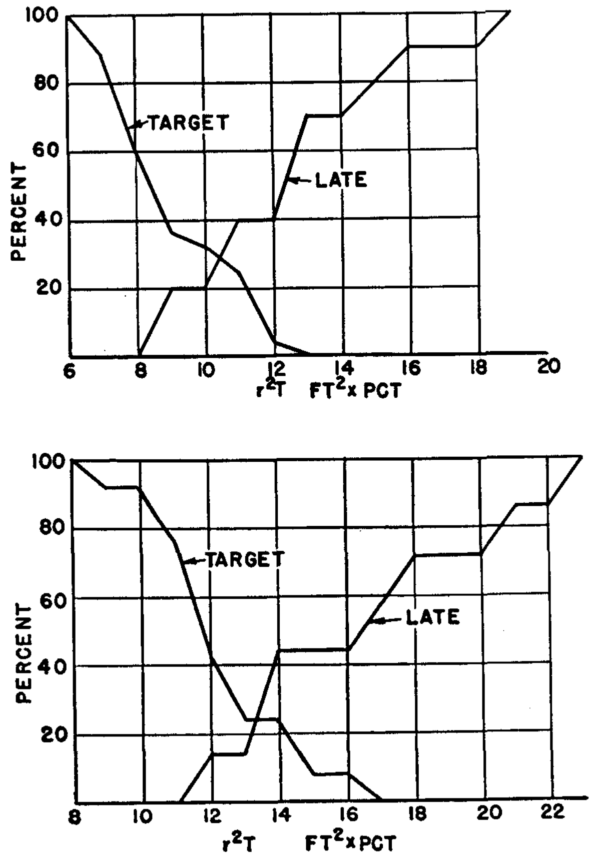


FIGURE 4. Correlation of laboratory and field test results for T-4 fuzes with substandard pentodes. Rounds fired against 4x4-ft target. Top figures for units with Raytheon and Sylvania pentodes. Bottom figure for units with Sylvania pentodes.

fuze is expected to be inversely proportional to the laboratory threshold, T. The magnitude of the target signal is assumed to vary inversely as the square of the distance of passage, r^2. Therefore, the percentage of functions on target is expected to decrease as the product, r^2T, increases, while the percentage of rounds which fail to function on the target increases. Only late functions and self-destructions are counted as failures to function on the target for the purpose of this correlation, since duds were probably dead fuzes, at the time they passed the target. The target curve in Figure 4 gives the percentage of fuzes which functioned on the target for all r^2T values greater than the value for a given point. The late curve gives the percentage which functioned late or by self-destruction for all smaller values of r^2T.

If there were no correlation between laboratory and field data, both the target and late curves would be horizontal lines at 50 per cent. If there were perfect correlation, the two curves would fall to zero at the same point on the abscissa scale. Thus Figure 4 indicates considerable correlation. The percentage value at the point of intersection may be taken as the percentage error in correlation.

Some factors which account for errors in correlation are:

1. The magnitude and shape of the target signal would vary somewhat from round to round at constant radius of passage due to variations in projected area of the target with position of the trajectory relative to the target.

2. There is some radial asymmetry of fuze sensitivity; hence the radius of action would vary as the rocket rotates in flight. The threshold is measured at a particular radial angle which is generally not the same as the angle at which the fuze sees the target.

3. There is some variation of frequency response among individual fuzes of a given type; therefore, there is variation of the ratio of 60-c threshold to target sensitivity.

4. Microphonics and ground light variations are a variable percentage of the required firing signal. Round-by-round variation of rocket vibration varies the microphonics level. Ground light variations may change continually with sun position and cloud conditions.

8.4.4 Tests against Series of Targets at Blossom Point

The four-target array has been described in Chapter 7. Two tests with standard and modified fuzes were made against this target, but in only one were trajectory conditions adjusted properly to give a measure of fuze sensitivity.[38]

The results of this test are in Table 3. The modified fuzes (designated RPEB-2) are divided into four groups according to the type of pentode in the

TABLE 3. Results of field tests against series of four targets at Blossom Point, October 2, 1943.*

Units	No. fired	Proper function	Early	Dud	Score	No. on target 1 2 3 4	Average thresholds at normal light level
RPEB-2 Hytron pentode	20	19	0	1	95%	0 1 16 2	0.98
RPEB-2 Raytheon pentode	19	18	0	1	95%	0 3 14 1	1.06
RPEB-2 Sylvania pentode	20	17	2	1	85%	0 3 10 4	0.85
RPEB-2 GE pentode	20	16	4	0	80%	2 5 9 0	0.54
MC-380 Hytron pentode	30	30	0	0	100%	0 0 26 4	0.92

*Target 1: 3x4 ft at approximately 75-ft radius.
Target 2: 4x11 ft at approximately 75-ft radius.
Target 3: 3x5 ft at approximately 30-ft radius.
Target 4: 3x10 ft at approximately 30-ft radius.

amplifier. The differences between target distribution among the four targets indicate that the four-target array successfully distinguished differences in sensitivity by type of fuze. Units with General Electric [GE] pentodes were most sensitive; almost half were triggered by the first two targets. A further indication that this was the most sensitive group is given by the fact that it had the highest percentage of early functions. The standard T-4 fuzes were least sensitive.

The units with GE pentodes were also shown most sensitive by laboratory threshold measurements (60-c test). Differences in average threshold were less pronounced and did not correlate directly with the relative sensitivities indicated by the target array. Better correlation would probably have been established had variations in target passage distance been taken into account.

On the tests with the standard T-4 fuzes, the 26 rounds which functioned on the third target (3x5 ft) passed that target at radii ranging from 25 to 50 ft. None of the standard fuzes functioned on the second target, which provided a peak obscuration of about 1.8 per cent. The peak obscurations by the third target for the range of passage distances 25 to 50 ft were approximately 4 to 2 per cent respectively. Thus the minimum pulse on which any fuze operated was about 2 per cent. A few which failed to function on the fourth target passed the third at distances of 35 to 40 ft, indicating that occasional fuzes may fail to function on pulses of about 3 per cent. It has been shown (see Chapter 4) that the threshold for field pulse targets is generally 2 to 3 times greater than the laboratory threshold measured at 60-c, continuous, alternating light signal. The 60-c threshold of T-4 fuzes averages about 1 per cent. Thus the results against the four-target array are in general agreement with expectations.

8.4.5 Functions on Poles during Acceptance Tests

Analysis of the burst position data of about 300 rounds of production T-4 fuzes, fired in acceptance tests on the North Range at Fort Fisher, showed that 64 per cent of the proper functions had fired against the front poles rather than against the large cloth piece target. A typical plot of the locations of the bursts for one lot acceptance test is shown in Figure 5. The view of the burst positions from above shows 8 bursts lying in a cluster approximately 25 degrees ahead of the poles. Obviously, these units functioned against the poles before they saw the cloth target. Similarly, the side view shows that two units passed the poles and functioned against the cloth target.

The pulse from the poles is due largely to the part of the poles above the horizon, relative to the rocket trajectory; therefore, the magnitude of the pole signal decreases with increasing height of the trajectory above the ground. The distribution of functions between poles and cloth target for about 300 rounds is shown in Figure 6. Up to 40 ft from the ground, approximately 90 per cent functioned on poles. It may also be seen that as the trajectory height increased the proportion of pole functions decreased to zero at 65 ft or higher.

The amplitude of the obscuration pulse as a function of trajectory height is shown on the right side

[redacted]

of Figure 6. The curves were obtained by computation. Maximum pole signals were obtained on rounds which passed exactly midway between the poles and saw both poles simultaneously. Minimum signals were obtained when the trajectories were sufficiently off center laterally to receive distinct successive signals from the two poles. The curves for the right pole and left pole are the per cent signal for the separate poles on rounds which passed midway between the poles. Actually, on off-center rounds on which the fuze would see the poles separately, the signal from the near pole would be larger, and from the far pole smaller. The lateral dispersion was small enough so that the signals from the two poles probably overlapped, at least in part, on most rounds; hence the firing signals were generally between the both pole curve and the one pole curve. In the threshold zone for pole functions, 40 to 65 ft above the ground, the pulse amplitudes were in the range of 1.5 to 3 per cent.

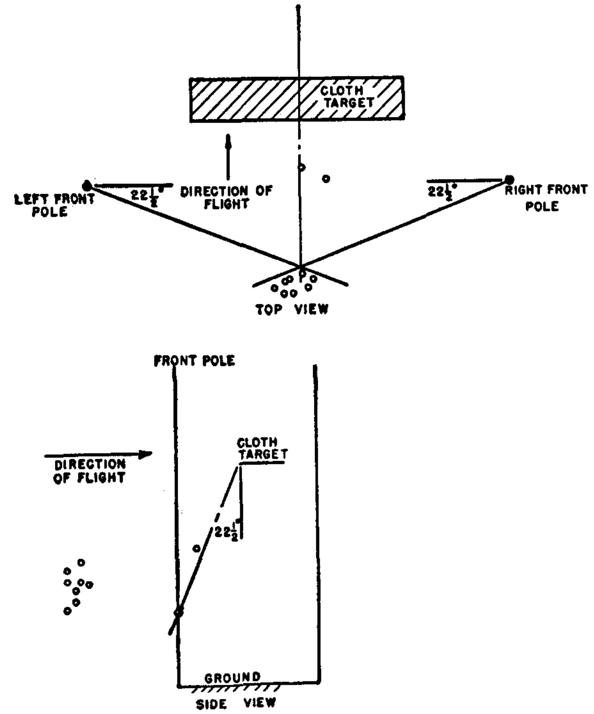


FIGURE 5. Top and side view of burst positions on rounds fired in lot acceptance test at Fort Fisher Proving Ground. Small circles indicate positions of bursts. Scale: 1 mm per ft.

Pole pulses reached their peak amplitudes about 8 milliseconds after the obscurations started. For this pulse time, the thresholds are 2 to 3 times greater than the thresholds measured at 60 c in the laboratory (see Chapter 4). Thus the pole function firing signals of 1.5 to 3 per cent are in reasonable agreement with the average 60-c threshold of about 1 per cent.

8.5 SUNFIRING TESTS ON T-4 FUZES

The susceptibility of the T-4 fuze to firing on seeing the sun was known from the beginning of the development. However, no experiments were conducted on sun angle limits until the fuze was well along in production and consideration was being given to the development of improved models. Field tests in which the fuzes were intentionally fired to see the sun are summarized in this section.[19,36]

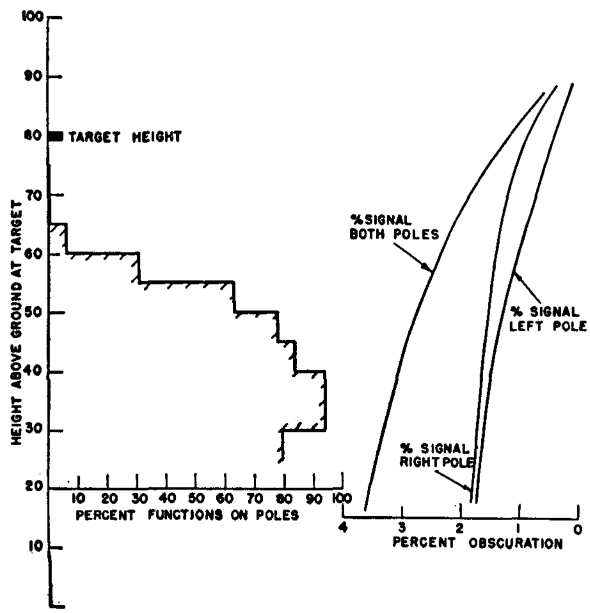


FIGURE 6. Per cent of light obscuration and per cent of fuzes which functioned on "seeing" poles which supported target as function of height of rocket trajectory above ground in region of target.

The aims of the tests were: (1) to determine the sunfiring properties of the fuze, (2) to obtain data for use in the development of the nonsunfiring fuzes. The tests involved the firing of 145 rounds "through the sun." One hundred rockets were fired at such an angle of elevation that they would ride several seconds before the sun came into the field of view. Forty-five rounds were fired to see the sun immediately at arming. Observations of time of function and ballistic calculations to determine the direction of flight at the time of function permitted determination of the sun angle (angle between the sun and the center of the field of view of the fuze) at the time of function. Use of a 44-ft long projector limited initial angular dispersion of the rockets and hence permitted reasonably accurate knowledge of the trajectories.

The probability of sunfiring as a function of sun angle, based on the tests, is shown in Figure 7. The

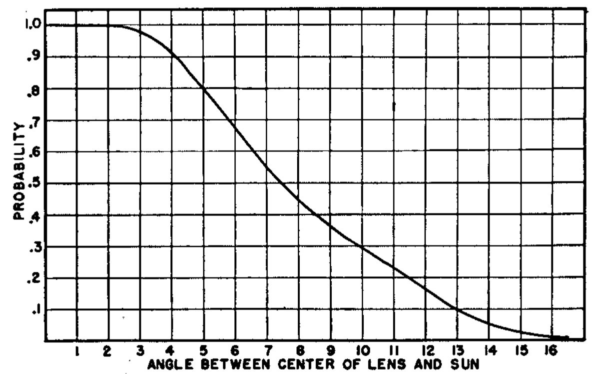


FIGURE 7. Probability of sunfiring versus angle between sun and center of field of view of fuze.

maximum sun angle at which sunfiring occurred was 16 degrees. The curve is based on the 100 rounds fired to pass into the sun sometime during the flight. There were 7 duds in the 100 rounds, but, since there was no means of determining whether these fuzes were alive after riding through the sun, these rounds were discarded. Seven duds per hundred is higher than average for this type of fuze; thus it is possible that the maximum probability in Figure 7 should be about 0.97 rather than 1.0. However, this difference is negligible for practical purposes.

The 100 rounds discussed above were fired with fuzes from which the self-destruction feature was removed. The 45 rounds which were fired to see the sun immediately at arming had fuzes with the self-destruction feature. The results were

4 self-destruction;
32 functions on arming (at about 0.75 sec);
8 functions at 0.3 to 1.5 sec after arming;
1 nonfunction.

On the basis of these tests, it is clear that the T–4 fuze cannot be used for ground-to-ground firing, except at very restricted azimuths. (See Section 8.7.2 concerning tests on sunproofed modifications of the T–4 fuze.) For plane-to-plane application, the use of the fuze is feasible since the change in direction of flight during the useful target range is small. Computations on the basis of Figure 7 have shown that an average probability of sunfiring for random orientation of an initially horizontal trajectory in plane-to-plane firing is 0.14. This probability varies somewhat with season, time of day, geodetic latitude, and average firing range, but it is in no case large enough to preclude use of the fuze. The probability can be reduced to zero by firing when flying in such directions that the fuze will not see the sun.[39]

8.6 REVISIONS OF T–4 CIRCUIT AND OF LABORATORY TEST REQUIREMENTS

8.6.1 Revised Circuit

Considerable engineering was done on the T–4 fuze after basic specifications had been established and production started. This section summarizes field tests, intended to evaluate various proposed changes from the original standard design and specifications. The main object of the work was to relax certain requirements to facilitate production.

In general, it was found that:

1. As long as the amplifier-gain characteristics remained approximately the same, field scores were unimpaired. In particular, increased gain at lower frequencies increased the number of random functions.

2. Increased amplifier gain obtained with more sensitive pentodes increased the number of early functions. This result indicated that the gain in the standard fuze was approximately optimum for reliable performance. (See references 7, 8, 10, 11, 12, 13, 15, 28, 37.)

A revised circuit designated as RPEB–2 (Rocket, PE, Battery, second model) yielded scores comparable with those obtained with standard T–4 fuzes. It was not expected that the revised circuit would improve performance under standard conditions, but rather that the circuit would be easier to build and also give as good or better performance than the previous model, under conditions of long storage.

The circuit included a photocell of greater sensitivity (designated 1P24) and accordingly allowed the use of lower input impedances for the amplifier. This, in turn, permitted the use of pentodes with lower input impedance and reduced the requirement that the pentode maintain a high input impedance over extended periods, i.e., remain "gas free." (See references 14, 31, 33, 38.)

8.6.2 Evaluation of Laboratory Microphonic Test

Approximately 50 T–4 fuzes which failed the laboratory test for microphonics were fired in comparison with standard fuzes. There was no correlation between the magnitude of the microphonics in the laboratory test and the incidence of early function. On the basis of this test, the microphonics test appeared to be inadequate.[16,17,41]

8.7 TESTS ON EXPERIMENTAL MODEL ROCKET FUZES

This section summarizes the field test results on models of photoelectric fuzes which did not go into factory production. The condenser model, zero stage model, and sunblocking model were under development at the time development work on photoelectric fuzes was stopped. Other improved models (double photocell, generator-powered, etc.) were under development in the laboratory, but had not reached the stage for field tests. Field tests on T–4 type fuzes with multistage amplifiers and on rocket fuze types which preceded the T–4 are summarized.

8.7.1 Condenser-Powered Fuzes[45,49]

The condenser-powered fuze, described in Chapter 5, has the advantage that it requires no B battery. However, an external battery is required to charge the storage capacitor in the fuze just before the rocket is launched.

One hundred condenser-powered fuzes were constructed of which 31 were fired in field tests.[5,6,23] The results were: 29 target functions (93.5 per cent); 2 early functions.

8.7.2 Sunproofed Fuzes

The development work on fuzes which would allow the sun to pass through the field of view without firing had two phases: (1) simple circuit modifications of the T–4 fuze, (2) basic changes, such as use of the two photocells and double lenses (see Chapter 5).

Sunproof modifications of the T–4 were developed and field tested. Basic new types were under development in the laboratory, but did not reach the stage of field testing.

During the period of major work on the sunproof models, interest in rocket proximity fuzes was directed toward the ground-to-ground (rocket barrage) application. While the PE fuze was suitable for air-to-air use in spite of sunfiring (see Section 8.5), this defect made it entirely unsuitable for ground-to-ground firing, since in this use the fuze would see the sun at some point in its trajectory under most firing conditions.

The development of a sunproof fuze for the ground-to-ground application was simpler than for air-to-air use for two reasons:

1. The ground-to-ground fuze could be designed to become inoperative when it saw the sun and to revive when the sun passed out of the field of view. This required a simpler design than for a fuze which would operate properly even with the sun in view. For air-to-air use, the latter more difficult design would have been required.

2. The light levels encountered on approach to ground are considerably lower than at high altitudes. This simplified the problem of blocking the effect of the very high light level of direct sunlight.

The tests, described below, on sunproof modifications of the T–4 fuze showed successful elimination of sunfiring. However, these tests also showed that the basic design of the T–4 fuze is not satisfactory for ground approach use, since, under some terrain conditions and angles of approach, the light variation seen by the fuze is so small as to result in duds or very low burst heights. Several tests were carried out in an attempt to find a target which would trigger the fuzes on approach to ground. No really satisfactory target was found, as shown in the results summarized in Table 4. The ranges were selected so that in each case there would be some period during the day when the fuze would not see the sun on any part of the trajectory. This permitted evaluation of the effect of the sunproofing feature on normal performance.

These results indicated that the T–4 could be successfully modified to be sunproof with no loss in ground approach performance, but that ground approach triggering depends on the angle of descent. At the low firing angle, the score on this test was about 60 per cent, while at high angle it was practically zero.

TABLE 4. Field tests on sunproofed units.

Test No.	No. of special fuzes	No. of standard fuzes	Firing elevations (degrees)	Functions			
				Random	On sun	On approach	Dud
1	25	..	20	1	1	0	23
	..	13	20	0	12	0	0
	..	9 *	20	0	0 *	1 *	8 *
2	12	..	61	4	1	2	5
	..	4	61	..	2	..	2
	..	23 *	61	6 *	0 *	0 *	17 *
3	13	..	11	0	1	7	5
	..	2	11	0	2	0	0
	..	21 *	11	0 *	0 *	13 *	8 *

* Indicates control rounds fired at a time of day when, for the trajectory chosen, the fuze could not see the sun.

The development of sunproof fuzes required determination of the type of light signal seen by the fuze when it passes into the sun. The sun signal is a high-amplitude, low-frequency alternation, which is caused by rocket yaw. The following field-test information was obtained on the rate and amplitude of yaw of the M-8 rocket:

1. Rockets equipped with smoke tracers were fired from an airplane and the trajectories were photographed.[4] Measurements of the photographic records gave frequency of yaw, but not the amplitude. The average frequency of 11 rounds was 4.4 c.
2. Yaw reporters (see Section 7.5) were built, in which the photocell current from a T-4 optical system determined an audio frequency, which modulated the reporter's radio transmitter. The audio-frequency modulation was roughly proportional to the photocell current. The record from a single test showed an average yaw frequency of 3.5 c for the M-8 rocket.[20] The test was also expected to yield data on the amplitude of yaw, but the results were uncertain in this respect.
3. An analysis of the sun angles at which T-4 fuzes functioned when fired into the sun provided rough data on yaw amplitude. The results indicated an average yaw amplitude of about 9 degrees.[36]

During the development of sunproof modifications for the fuzes, a laboratory yaw test machine was built, which permitted roof tests to determine the behavior of fuzes while oscillating relative to the sun at any desired frequency and amplitude. The field data on yaw amplitude and frequency provided a guide as to the minimum frequency and amplitude at which modified fuzes should be sunproof on the yaw machine.[40,42]

8.7.3 Results of Early Tests

Reference is made to the bibliography for results of evaluation tests on earlier models of photoelectric rocket fuzes.

Tests on low-sensitivity fuzes without amplifiers are covered in references 43, 44, and 48. Tests on a fuze with a three-stage amplifier (BR model, or M-1), intended for use on British 3.25-in. rocket, are covered in reference 46. The BR model became obsolete with the development of the one-stage model used in T-4 fuzes.

Tests of fuze performance on rotating rockets are covered in references 24, 25, and 35.

Reference 2 covers other miscellaneous tests.

8.8 TEST OF FUZES MOUNTED ON BOMBS

8.8.1 T-4 on Bombs

A special version of the T-4 was prepared for mounting on bombs. The nose of the fuze was mounted in a T-50 bomb fuze housing on the nose of the bomb. The battery and switch were mounted in a special bakelite housing in the tail of the bomb. A flexible cable, passing through a tube through the center of the bomb, connected the fuze nose to the battery and switch. The switch was modified to be actuated by withdrawal of an arming wire.

This modification of the T-4 was intended for use in tests and training in the use of bomb-tossing equipment.[c]

The modified fuzes operated satisfactorily on ground approach when dropped into wooded areas.[27]

When tested in toss bombing maneuvers against

[c] See Division 4, Volume 2.

[redacted]

a PQ–8 radio-controlled target plane the results indicated a lower than expected sensitivity. Otherwise performance was satisfactory. The low sensitivity (ROA of 15 ft) may have been due to a low approach velocity. The amplifier of the T–4 fuze was designed to give optimum sensitivity at approach velocities somewhat over twice those encountered in this test.[30]

8.8.2 Generator-Powered Bomb Fuzes

Only 15 generator-powered bombs were available for field testing before termination of the PE project. Two of these fuzes, designated T–52 or BPEG, were tested on M–57 and M–58 bombs by dropping into a wooded area. There were 8 proper functions and 2 duds.[18,21]

Limited test of the self-destruction element in the BPEG fuzes show 100 per cent performance.

8.8.3 Early Bomb Fuzes

The initial period of photoelectric fuze development in this country was directed toward development of bomb fuzes intended for plane-to-plane bombing. The various models developed became obsolete after the development of the T–4 fuze and of generator power supplies. Results of proving ground tests on the early bomb fuzes are covered in detail in reference 1.

A summary of the final evaluation tests on the first bomb fuze developed is of interest. These tests were made in September 1941. Twenty fuzes were dropped against a radio-controlled drone plane. The drone had a wing span of 25 ft and was painted bright yellow. The fuzes were dropped on Mark XII bombs with the bomber at 8,000 ft and the drone at 6,500 ft. Results were: 11 on target within passage distance of 100 ft; 1 early; 5 self-destruction on rounds which passed too far from the target; and 3 duds.

If self-destruction on passage at large radii, as well as target functions, are considered to be proper functions, the score on the 40 rounds of model C fuzes was 82 per cent proper. The radius of action against the small target was in the neighborhood of 100 ft.

Chapter 9

MISCELLANEOUS PROJECTS OF DIVISION 4[a]

9.1 ROCKET DEVELOPMENT[b]

9.1.1 Test Rockets

To insure an adequate supply of rockets for its own use, Division 4, NDRC, then Section E, Division A, initiated the development of rockets in June 1941. As a result, a satisfactory $3\frac{1}{4}$-in. rocket was developed and produced in experimental quantities. In addition, a target rocket (see Section 9.1.2), later used extensively in the training of antiaircraft crews, was developed.

When Section E began the development of proximity fuzes for rockets, it was apparent that testing of the fuzes would require substantial numbers of rockets. Few British rockets were available, and only a few rockets per day were being made in this country. All these were being used for experimental purposes by the rocket development groups. Thus, to insure an adequate supply of rockets for its own use, Section E began work on rockets. The initial plan was to design and to produce in small quantities a satisfactory rocket to serve as a vehicle for the various rocket fuzes. No thought was given to the design of a rocket for use as a weapon.

The early radio proximity fuze research program was based on the use of the British long-range rocket and the modified versions under development by Division 3, then Section H, Division A, NDRC. Certain physical sizes, such as the $3\frac{1}{4}$-in. diameter, were therefore fixed and carried through subsequent designs.

A number of designs of various lengths and nozzle diameters were made in the Bureau of Standards shops and tested statically and ballistically. The most satisfactory design was produced in sufficient quantity for preliminary rocket and fuze testing. As increased numbers were required, they were purchased from the Central Scientific Company of Chicago, Illinois. For purposes of coded reference, they were thereafter referred to as Cenco motors.

The motor was designed to be made from standard stock material without special machinery. The body was made from $3\frac{1}{4}$-in. OD by 0.120-in wall steel tubing closed at the forward end with a plug welded to the tube. At the nozzle end an annular internally threaded ring was welded. The nozzle was machined from solid bar stock threaded to fit into the ring welded to the tube. Four sheet steel drag fins $\frac{1}{16}$x$2\frac{1}{2}$x12-in. long were welded to the tube. The entire assembly was $24\frac{3}{8}$ in. in length.[6]

A wire cage, designed to hold the sticks of propellant, was fastened to the inside of the closed end of the motor. This consisted of six $\frac{1}{8}$-in. diameter wires welded to a ring. Three sticks of propellant were slipped onto each wire. A base plate was placed on the projecting ends of the wires, and two nuts were screwed onto each wire. The plate was then bolted to the inside of the rocket motor. This securely held eighteen sticks of $\frac{7}{8}$-in. OD by $\frac{1}{4}$-in. ID by 5-in. long propellant, which was fired by an electric detonator enclosed in a silk bag of black powder. A photograph of this rocket and its components is shown in Figure 1.

Figure 1. Test rocket (3.25 in.) showing motor body with fins attached and nozzle directly below. Loaded power cage, black powder igniter with enclosed electric detonator, bare wire cage, and representative samples of propellant are also shown.

[a] Most of the projects summarized in this chapter were either undertaken in cooperation with other divisions of NDRC or initiated by Division 4 and later transferred to other divisions. For these reasons, the projects in this chapter are described with more than usual historical detail.

[b] This section was prepared by Clarence B. Crane of the Ordnance Development Division of the National Bureau of Standards.

The shape of the nozzle is the most important part of the rocket design.[e] However, since the type of powder and the burning area exposed are the largest factors involved in the calculation of the nozzle diameter, the powder type and size available dictated this design. The nozzle therefore was made $1\frac{3}{8}$ in. in diameter with an 18-degree included angle opening.

Average values of the pertinent characteristics of this motor, when carrying a proximity fuze and fired at an angle of 45 degrees are as follows:[2-5]

Burning distance	40 ft
Burning time	0.12 sec
Max velocity (ft per sec)	675
Acceleration (g)	175
Range	10,000 ft
Flight time	30 sec

9.1.2 Target Rockets

At the request of the Coast Artillery, a program to develop a rocket to be used as a training target for light antiaircraft weapons was initiated during August 1941. The development program was carried out jointly by Divisions 4 and 3 (then Sections E and H of Division A, NDRC). All design and testing was conducted by the staff members of both organizations with all construction work centered in Division 4's Central Laboratories at the National Bureau of Standards [NBS]. The requirements stated were that the rocket have a speed of 250 to 300 mph, reach an elevation of 200 to 400 yd, and that visibility be increased to allow a firing range of 500 to 2,500 yd.[1]

Several of the rockets developed and made at the National Bureau of Standards for use as vehicles in the proximity fuze program were regarded as suitable in so far as speed and range were concerned. Two methods to increase visibility were considered. The first idea was to increase the size of the fins to a point where they would be readily visible at the required range. The second idea was to attach a smoke trail which would burn during the greater part of the flight, giving off a dense, colored smoke. In some cases, both methods were used on a rocket. Noisemakers, such as bomb whistles, were also tried and discarded.

After several trials, a semicircular fin with a radius of 10 in. was designed. Two sheets of light gauge tin plate, cut into semicircular form, were fastened together at the periphery to form an envelope. This was slipped over a wood and metal frame which spread the open side of the envelope and resulted in a lightweight, streamlined rigid structure. Four fins were then fastened to each rocket by means of bolts welded to the rocket body. The fins were generally painted black, but trials were conducted with white, highway orange, and in some cases fins were left unpainted.[9]

Several sizes of $3\frac{1}{4}$-in. diameter motors were tried. The variation occurred in the nozzle diameter and length of motor. Amounts of powder used varied from 450 to 1,200 grams. To place the center of gravity at the forward end of the motor, various lengths of $3\frac{1}{4}$-in. diameter steel tubing were added, terminating in a pointed steel ogive. This extension tube was later shortened, and the ogive was weighted with iron filings.

At this point in the development, a test was conducted at Fort Monroe, Virginia, on October 11, 1941. Eleven rockets with semicircular metal fins, and loaded with 1,140 grams of powder, were fired at an angle of 45 degrees. For the six good flights, the following data were averaged:[1]

Flight duration	21 sec
Range	1,920 yd
Initial velocity	450 mph
Velocity at top of trajectory	170 mph
Velocity at end of trajectory	240 mph
Angle of projection	45 degrees
Angle at end of trajectory	63 degrees

Four flights were satisfactory but shorter, having a flight of only 16.6 to 18.2 sec. One motor exploded after a flight of only 12.6 sec.

The general opinion by observing Service personnel was that the rockets as tested would be very useful for target practice.

During this period some work had been done on a swaged nozzle. The Revere Copper and Brass Company had developed a method for mass producing the motor by swaging a thin wall steel tube to form a nozzle. Section E ordered from this company a number of target rockets based on the design data previously discussed. The result is shown in Figure 2.

Because of the speed and range requirements, the motor was specified as a 14-degree $1\frac{1}{2}$-in. diameter nozzle. The total length of the assembly was 66 in. The motor was $24\frac{1}{2}$ in. long and $3\frac{1}{4}$ in. in diameter. A cast iron hemisphere, mounted in the end, placed the center of gravity 5 in. forward of the leading

[e] For a full discussion of the problems involved, the reader should refer to the reports of Section H, Division A, NDRC.

edge of the fin. The 4 half-circle fins were interchangeable and readily mounted on the motor by clips and spring catches, making possible easy shipment and field assembly. Since the nozzle was formed directly in the tubing, the forward end was closed by an obturator cup, a steel plate, and a spring snap ring. The 7-wire powder cage was bolted to this closure plate. The forward end of the motor was threaded to connect directly to the body tube. Twenty-one sticks of propellant 7/8 in. OD by 1/4 in. ID by 5 in. long were fired by a squib or electric detonator enclosed in a silk bag with a small quantity of black powder.

At this stage of the development, Section E withdrew from the problem, and further work was carried on by the Coast Artillery, the Ordnance Department, Section H, and the Revere Copper and Brass Company. Later developments resulted in a rectangular fin structure and a shorter assembly. Eventually only three fins were used.

FIGURE 2. Target rocket assembled and ready for use.

Use of these rockets in the training of antiaircraft crews had become standard procedure by the end of 1942. All told, the Army procured and used several million such rockets.

LAUNCHER

The Central Laboratories (NBS) then undertook the design of a launcher or projector from which to fire the target rocket. This involved a pair of guide rails mounted on an automotive trailer-type chassis, with provision for elevating the rails, electric connections, and good tracking characteristics for highway towing. The guide rails were mounted on supports long enough to provide clearance for one fin to ride between the rails. The rail assembly was 11 ft long, and a method was provided whereby it could be withdrawn and fastened to the tow bar, making a shorter trailer for towing. The projector set in firing position is shown in Figure 3.[7,8]

FIGURE 3. Target rocket projector in firing position.

The L. and S. Welding Company of Baltimore, Maryland, received the first contract for the construction of a pilot lot. Engineers from the Bureau of Standards followed the initial production and, with the full cooperation of the contractor, successfully completed the design.

9.2 T–25 MORTAR SHELL[d]

9.2.1 Introduction

In connection with the development of radio proximity fuzes for trench mortar shells,[e] it was decided that the possible additional drag introduced by the special fuze might be appreciably reduced by redesigning the shell. It also appeared that redesign of the 81-mm shell would greatly increase its stability in flight. Accordingly, a project was undertaken, in cooperation with the Engineering and Transitions Office of NDRC, to redesign the 81-mm trench mortar shell. The redesigned shell was designated T–25.

9.2.2 Difficulties with Standard Shells

Requirements of the 81-mm mortar VT fuze were (1) that the fuze be interchangeable with the mechanical fuze without modification of the projectile,

[d] This section was written by L. M. Andrews of the Ordnance Development Division of the National Bureau of Standards.

[e] See Division 4, Volume 1.

and (2) that the use of the VT fuze should have a negligible effect on the ballistics of the projectile. These requirements become major design factors for a mortar VT fuze. This was apparent from a comparison of the relative sizes of the smallest VT mortar fuze and the 81-mm shell, M43A1. The T–132 fuze was approximately 1 lb heavier than the point-detonating fuze, and this difference in weight amounted to more than 10 per cent of the total weight of the round. (See Figure 6, Chapter 1, for view of T–132 on mortar shell.)

Since the minimum size and weight of the fuze were fixed by other factors, the ballistic problem resolved into a consideration of the aerodynamic drag and stability. It was probable that the VT fuze would change both these factors. A minimum drag is desirable in order to approach the corresponding range of the PD round. A high degree of flight stability is a necessity; low stability would mean a large yaw in flight, or a tendency to tumble, with a resultant large dispersion, short range, and malfunction of the VT fuze.

During the development of the mortar fuzes it became apparent that both of the above requirements could not be met with the existing 81-mm Service shells. Both the M–43 and M–56 have only marginal stability with the bakelite or aluminum point-detonating fuzes. With all VT designs, the stability was unsatisfactory. Preliminary wind tunnel measurements of drag and stability of mockup fuzes on the M–43 shell showed that the stability could be improved if the fuze had a large flat frontal area.[11] Later tests of various fuze models also indicated that perhaps satisfactory stability could be attained by use of a flat-nosed fuze.[12]

A flat front, however, has the disadvantage of increasing the drag by nearly 60 per cent, which in turn reduces the maximum range of the M–43 by 30 per cent. From the viewpoint of good ballistics, it would have been desirable to streamline the fuze contour for minimum drag and to gain stability by some other means. One possibility was to increase the weight of the fuze. This has the effect of moving the center of gravity farther ahead of the center of pressure and thus increasing the restoring torque of the shell. The increase in stability is not as large as may be expected, since this also increases the transverse moment of inertia of the shell, and hence a larger restoring torque is required to control any initial yaw. Also, any appreciable increase in weight would reduce the maximum range as well as increase the size of the fuze. Another method of attaining stability would be modification of the shell by the substitution of a new fin system or extension of the present fin by means of an adapter; however, the requirement of no modification of the round ruled out the latter method at this time, and dictated the attempt of attaining stability by means of a flat-nosed fuze.

Preliminary field tests of the M–43 with dummy fuzes indicated satisfactory stability; later tests of the T–132 fuze on the M–43 and M–56, however, showed an appreciable number of rounds with bad yaw and several instances of tumbling in flight. The range, of course, was comparatively short. Wind tunnel tests which were made on the T–172, another VT mortar shell fuze, indicated that it was still less stable than the T–132.[11] Modification of the fin system was a necessity with its use. Since it appeared very improbable that the ballistic properties of the standard PD fuze could be approached with any VT fuze design without modification of the shell, this last requirement was waived soon after experimental production was started on the T–132.

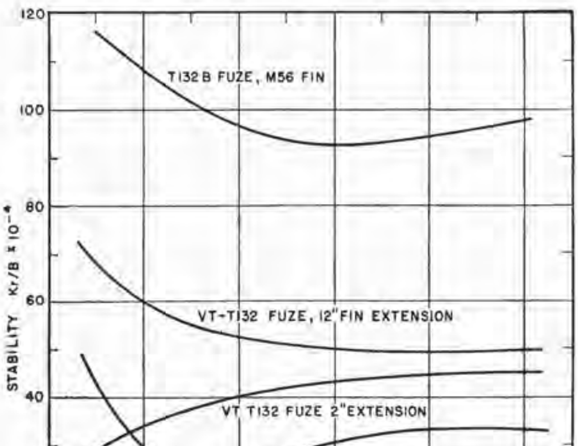


FIGURE 4. Stability of M–43 shell with various fuzings and tail assemblies.

With the M–43, two simple modifications were possible, either to extend the fin 2 in. by means of an adapter, or to replace the fin with that of the M–56. With the M–56 shell, it was also found that a 2-in. fin extension would result in satisfactory stability with either the T–132 or the T–172 fuze. Typical stability and drag characteristics of the two shells with various fuzes are shown in Figures 4, 5, and 6. In order to compare dissimilar shells, the stability has been expressed in terms of Kr/B, in which K is the restoring torque per degree of yaw, B is the transverse moment of inertia, and r is the distance from center of gravity to the end of the

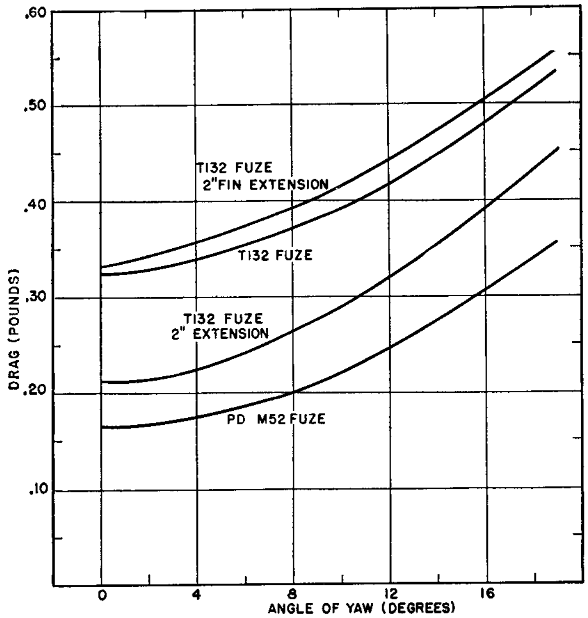


FIGURE 5. Drag of M–43 shell with various fuzings and tail assemblies.

stabilized fin.[15] Figure 4 shows the effect of the T–132 fuze on the stability of the M–43 with and without fin extensions, as well as the effect of partially streamlining the fuze. The T–132B fuze is identical with the T–132 except for a slightly smaller diameter turbine and a partially streamlined turbine cover. Corresponding drag curves are shown in Figure 5. The M–56 characteristics are shown in Figure 6. The 2-in. fin extension of magnesium alloy weighs approximately 0.1 lb, and hence has little effect on the weight of the shell. It is apparent that stability can be increased by this means with very little increase in drag and/or in weight; in fact, it allows the fuze to be further streamlined for minimum drag. Range tests indicate that, if the drag of the VT fuze could be reduced to the same value as that of the PD fuze, the maximum range of the M–43 would be only 5 per cent less due to the difference in weight.[13]

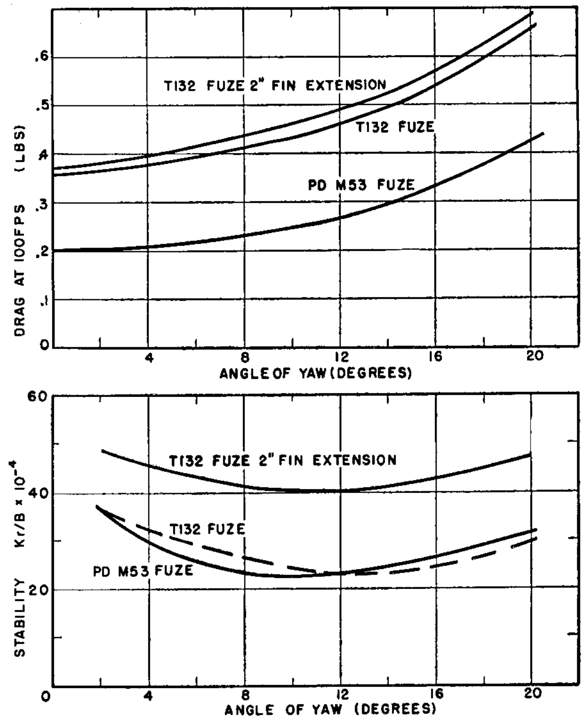


FIGURE 6. Stability and drag of M–56 shell with various fuzings.

9.2.3 T–25

Another solution to the ballistic problem was the use of a new shell so designed that it would be stable with either the PD or VT fuzes, without modification. We have seen that the desired interchangeability could not be attained with either of the existing 81-mm shells. Although the M–43 and M–56 could be made stable by changes in the fin system, there are other objections to the use of the modified shells. The M–43 has a relatively small HE capacity, and hence there is a question of the economics of its use with the VT fuze. M–56, on the other hand, has a relatively short range. The opportunity of improving the ballistics of the shell presented itself when members of the Engineering and Transitions Office suggested that, in connection with its program of setting up new facilities for mortar shell production, it would be possible to experiment with a new shell. Accordingly, the Bureau of Standards was asked to submit a design for an 81-mm mortar shell with improved ballistic properties, without too much sacrifice in HE capacity or range.

The time factor was the main element of control. Other design factors were the availability of the M–56 aluminum fin assembly with good ballistic

[redacted]

characteristics, and the desirability of using a relatively thin wall. Panel tests had indicated that for fragmentation purposes the thin wall of the M–56 was more efficient per pound of weight than the heavier wall of the M–43.

For long range, the shell must be well streamlined. Since it was desirable to use the M–56 fin system and a thin-walled shell, the length of the body became the controlling factor of both weight and stability. Maximum range, in turn, depended primarily on the weight. As neither the desired range nor weight were specified, an arbitrary compromise was made by tentatively fixing the length of the body at 12 in. This resulted in a shell approximately 3 in. shorter than the M–56, with 75 per cent of its HE capacity, and weight midway between that of the M–43 and the M–56.

Preliminary models were made of 2 types, differing only in the nose contour, as shown in Figure 7. Type X has a nose contour identical with that of the M–56, whereas Type Y is more like the M–43. Wind tunnel tests were carried out to determine drag and stability of these models with the PD and VT fuzes. The results were very encouraging. The

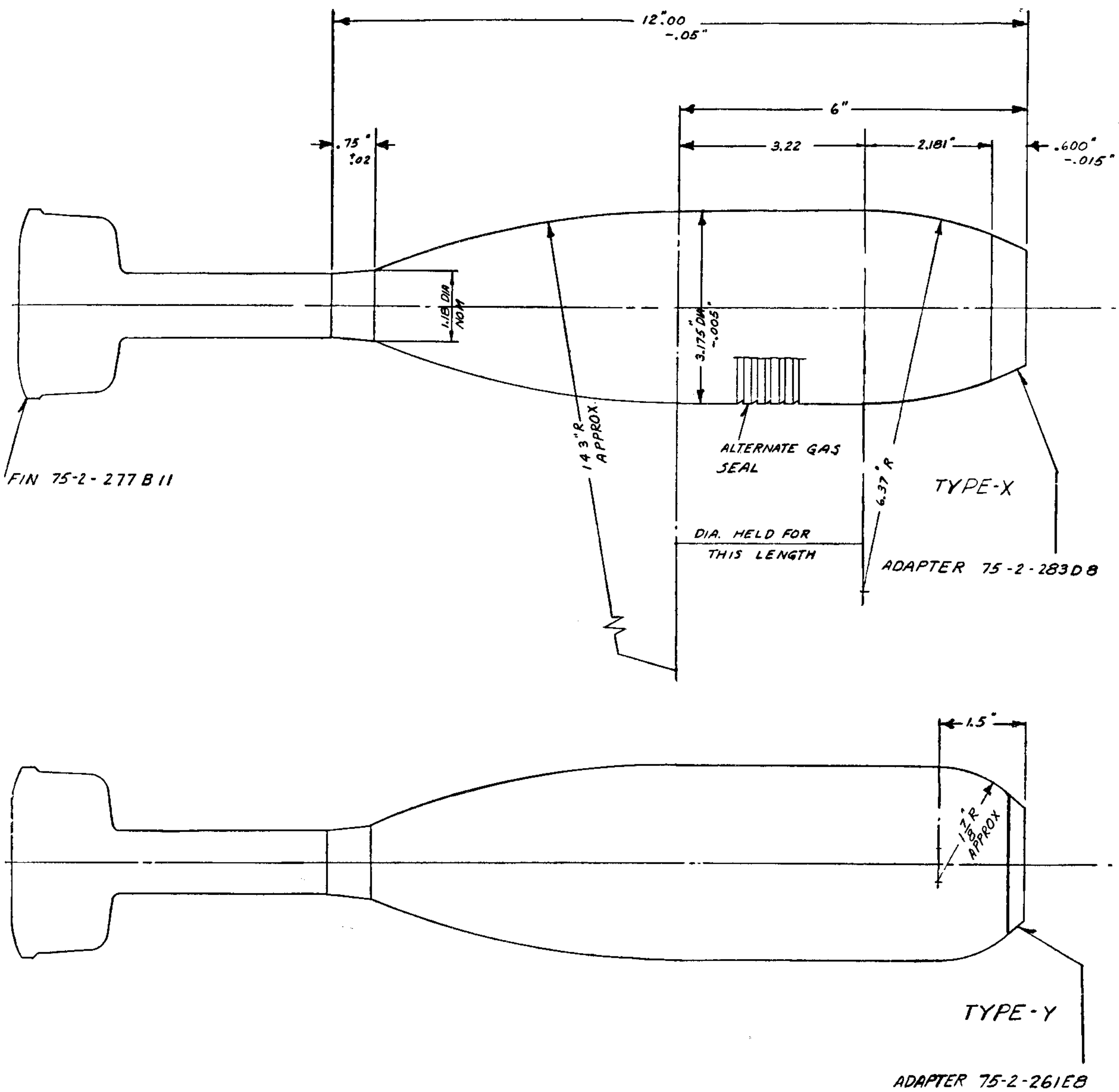


FIGURE 7. Proposed contours for T–25 mortar shell.

[redacted]

new shell showed better stability than either the M–43 or the M–56 even when these shells were modified by means of a 2-in. fin extension. Aerodynamic drag promised not to be nearly as low as that of the M–43. It would have been advantageous to carry out further wind tunnel tests to study the effect of other body contours and lengths upon ballistics. However, time did not permit this. The contour designs, as shown in Figure 7, were submitted to OSRD 3 days after the assignment. The shells were shown without the bourrelet, as it was anticipated that this feature might be eliminated by means of the proper shell diameter. (This was later verified by range tests at the Clinton Proving Ground at the University of Iowa, on modified M–56 shells.) Other factors, such as exact wall thickness and inside contour, must of necessity be determined by field test and, to some extent, by manufacturing expedients. Since there was very little difference between the Type X and Y shells aerodynamically, the choice of contour would depend on the desired fragmentation or penetration properties.[14]

Under the direction of the Engineering and Transitions Office, 20 experimental lots of the T–25 shells were made at the Kewaskum Aluminum Company, each lot differing in either nose contour, wall thickness, inside contour, or length. For the purpose of fragmentation tests, wall thicknesses were varied from approximately 0.075 to 0.130 in. Except for lots 18 and 12, all shells were either of the X or Y type. Lot 18 was made with the body length of 11 in. instead of 12 in. Lot 2 was made with a very blunt nose contour with an outside radius of approximately 1 in.

Samples of each of the lots were analyzed at the National Bureau of Standards for ballistic properties with the PD and VT T–132 fuzes.[15,18] Metallurgical tests were also performed on the steel.[19] As the shells were made with temporary tools and did not represent the desired product in several minor respects, only a preliminary comparison could be made of the various types. Slight irregularities of contour may have an appreciable effect on drag and on the location of center of pressure. In general, the wind tunnel tests substantiated the measurements on the preliminary models. Due to conservative estimates of the center of gravity of the models, stabilities proved to be even higher. If stability is expressed in terms of the ratio of the distance between the center of pressure and the center of gravity to the overall length, the T–25 shells have a factor of 12 to 13 per cent with either PD or VT fuzes. This is to be compared with 7 per cent for the M–43 with a PD fuze, and 11 per cent with the T–132 fuze and a 2-in. fin extension. Stability of the M–56 is even lower than that of the M–43. Variations in wall thickness and nose contour, as represented by the various lots tested, had but slight effect on stability.[16,17]

Figure 8 shows graphically the stability of the T–25 shells compared with the M–43 and the M–56. The effect of a further compromise in weight of the round in order to gain range was shown by lot 18. With a body length of 11 in., the drag is reduced to

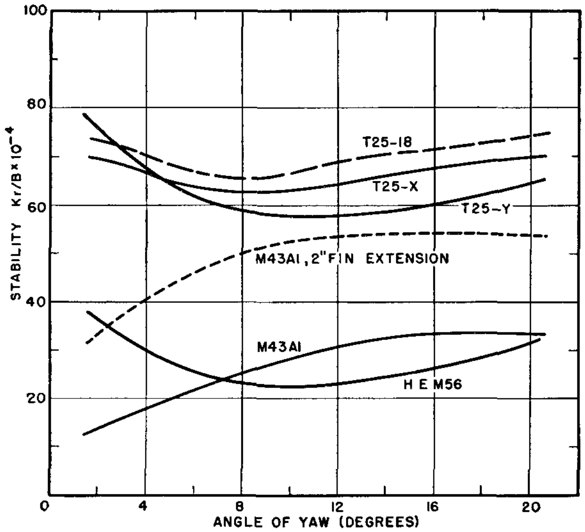


FIGURE 8. Stability of models of T–25 mortar shell, shown in comparison with M–43 and M–56 shells.

that of the M–43. A shell of this length, with a wall thickness of 0.080 in., would have approximately the same weight and range as the M–43, but with more than double its HE capacity (capacity is 68 per cent of that of the M–56). Stability is, of course, further increased by the reduced body length.

Shells of the lot 2 type proved of interest also. This shell, with a relatively blunt nose, should have a better fragmentation pattern. The drag as measured at 100 ft per sec showed no increase over that of the other shells.

All the wind tunnel tests indicated that a shell of the T–25 type, regardless of the exact wall thickness or nose contour, should have a very stable flight with any of the present PD or VT fuzes. The tests also showed that a T–25 shell would allow for com-

[redacted]

plete streamlining of the VT fuze; hence the difference in range of the PD and VT rounds could be reduced to a minimum.

Range tests of a small number of lots 3, 12, and 17 shells were attempted; however, the data were insufficient for reliable comparisons.[10] A maximum range of approximately 3,300 yd at 5 increments of charge was indicated. Due to the limited data, no estimate of dispersion could be made. A complete evaluation of the T–25, including fragmentation, range, and dispersion data, had not been completed at the end of World War II.[f]

9.3 THE MAGNETIC FIELD MACHINE[g]

9.3.1 General

The magnetic field machine is an apparatus that was developed for the use of the Naval Ordnance Laboratory in connection with the protection of ships against magnetic mines. The design, construction, testing, and operation of the machine is fully covered in reference 20, and only a brief description of the main features is given here. The first machine was installed in the Naval Ordnance Laboratory in April 1941. Subsequently, the Navy ordered additional machines for other locations.

9.3.2 The Problem and General Character of Its Solution

The machine was developed to provide a physical solution to a type of problem that had, for want of an easier method, been solved previously by tedious mathematical calculations. The problem is to determine the magnetic field intensity of a ship throughout a large volume of water underneath the ship, in order to determine whether the ship can pass safely over a magnetic mine. Magnetic mines of current design are lodged on the ocean bed and operate when influenced by any change in excess of a certain minimum change in the vertical component of magnetic intensity. The basic magnetic measurements that are made on a ship provide a map of the vertical component of magnetic intensity in a single horizontal plane slightly below the keel of the ship. If this plane is mapped over an area large enough so that there is a negligible total flux outside the mapped region, the field strength at all lower levels can be calculated from well-established laws of mathematical physics. The magnetic field machine was designed to reproduce, on a small scale, the field in the mapped plane, and hence (on the same small scale) the field at all lower levels. The machine incorporates search coils on an automatically driven carriage, and an automatic recorder for mapping the field throughout the useful range of lower levels.

[f] For further information on the T–25 shell, reference is made to reports of the Engineering and Transitions Office.

[g] This section was written by T. N. White of the Ordnance Development Division of the National Bureau of Standards.

9.3.3 Arrangements for Construction and the Overall Result

The construction of a magnetic field machine was first proposed by the Naval Ordnance Laboratory to Division A of the National Defense Research Committee in November 1940. A general consideration of design problems by the physicists of this division led to a plan of construction that involved many problems which arise in telephonic engineering. The basic design problems were presented to engineers of the Bell Telephone Laboratories in December 1940, and the detailed design and construction were worked out in collaboration with this company and the Western Electric Company. Testing was conducted at the National Bureau of Standards. The complete equipment and typical results were formally exhibited in April 1941. The results of tests of the machine indicated that the ratio of overall time required for the solution of ships' fields by the two methods—mathematical and physical—is between 10/1 and 20/1 in favor of the physical method.

9.3.4 Basic Design Considerations

An alternating magnetic field method was chosen on account of the ease of exploring the field with a small search coil, and its freedom from the effects of stray steady magnetic fields. A frequency of 270 c (180-pole alternator directly coupled to a standard 4-pole synchronous motor on 60-c power) was selected to avoid harmonics present in 60-c power supply. The field intensity in the ship's plane of measurement was reproduced by a stack of 4-ft single-layer coil solenoids 40 coils long by 20 coils wide (800 solenoids total). Hard rubber cores of rectangular section ($1\frac{1}{4}$x$\frac{7}{16}$ in.) with longitudinal ventilating slots were used. In order to avoid phase shifts due to coupling between coils, a high ratio of resistance to reactance was obtained by using fine alloy wire No. 37, tinsel-bronze, 168 turns per inch.

[redacted]

The resulting rather low current avoided contact difficulties in the associated switching mechanism. Power was supplied to the coils through a "panel bank" (modified from standard automatic telephone exchange equipment) from a special tapped transformer (center-tapped 60-volt secondary with taps every 0.3 volts each side of center). Three search coils (to allow mapping of all 3 magnetic field components if desired) were mounted on a belt-driven carriage. The output of any one search coil could be automatically recorded on a run through the magnetic field. The recorder was of the self-balancing potentiometer type, especially designed by the Bell Telephone Laboratories for an accuracy of 0.01 millivolt. The output of the search coil was balanced against a reference voltage obtained from the tapped transformer to minimize the effect of power supply variations.

9.3.5 Sample Results

Results obtainable with the machine are illustrated in Figure 9. The field of the ship from which the basic data were obtained was also computed by

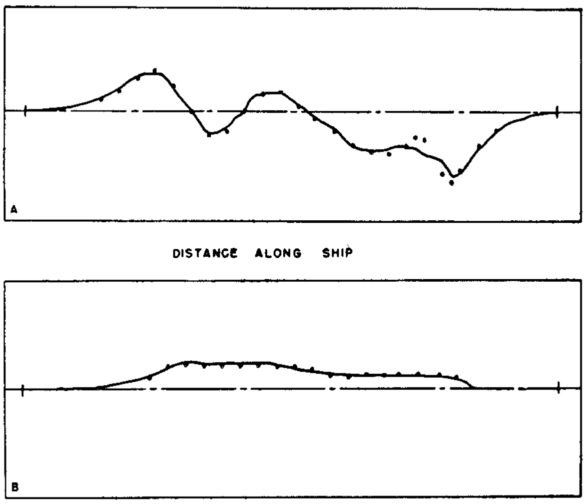


FIGURE 9. Sample signatures taken from field of ship (TU-12) which had already been solved by computation. (A) shows magnetic field as function of distance along ship at depth of 70 ft and 10 ft to starboard. (B) shows field of same ship at same depth but 130 ft to port.

the mathematical method, and these results are represented by dots on the diagram. It will be noted that the pattern of the computed intensities is somewhat more irregular, but the general agreement is very good. It is not known whether the differences arise from a slight "smoothing out" process inherent in the machine, or from irregularities arising from the assumption of discrete magnetic poles for the purpose of mathematical computation. There is fairly good reason to believe that the true field may be slightly less irregular than that given by the machine.

9.4 RADAR RANGING ON SHELL BURSTS[h]

Early in World War II, the British were reporting observations of radar echoes from shell bursts. Later our own radar operators reported the same phenomena. This led to an interest in the possibilities of ranging on shell bursts by radar means as an effective method of fire correction. Division 4 was requested by the Navy[21] to consider this application of radar to fire control and to make the necessary experimental investigations to evaluate its effectiveness. Work started in February 1942 and was stopped in October 1942, before completion, because of conflict with the effective prosecution of the proximity fuze development.

During this period, the available literature on the subject was abstracted, a program of investigation established, and several interesting experiments completed.[22,23] The objectives were twofold: (1) to determine the mechanism of echo production; (2) to specify proper shell fillers and radar equipment for most effective burst ranging. Objective (1) had not yet been reached when Division 4 found it necessary to stop the work.

The experimental program was run in close cooperation with Re4a of the Navy Department. The Navy provided facilities at Dahlgren, Virginia, and arranged for tests at Marine Barracks, New River, North Carolina, and at Camp Davis, North Carolina.

First preliminary experiments were made at Dahlgren, Virginia, to observe the echo from a static burst by means of continuous wave reflection. The echo was observed[22] and found to be of sufficient duration so that it could not be lost between radar pulses. This demonstrated that the echo observation did not appear to be a chance phenomenon.

In parallel with the c-w experiments, some theoretical work was done to see if ionization or fragments were the most probable source of the echo. It was decided that ionization probably accounted for most of the observed effect at low frequencies

[h] This section was written by Robert D. Huntoon of the Ordnance Development Division of the National Bureau of Standards.

[redacted]

(100 to 200 mc) and that fragments might be more important at microwave frequencies (3,000 mc). In the intermediate region, both might play a part.

In addition to providing the facilities at Dahlgren, Virginia, for the c-w tests, the Navy arranged for an SCR268 (200-mc) fire control radar with a 3-in. AA gun and 25 special rounds filled with magnesium powder.[22] The tests were made at Marine Barracks, New River, North Carolina. Arrangements were made to photograph the echo pulses on the range oscilloscope. Of 18 rounds fired for the record, with slant ranges varying from 7,000 to 12,000 yd, 1 failed to burst and 17 gave good echoes. The echo persistence was from 0.08 to 0.22 sec, indicating that the ionized flash was probably responsible for the echo. The radar did not respond to the shell in flight. Fluctuations of echo intensity during the echo interval were observed.

At the conclusion of the New River tests, a program for further investigation was suggested.[22] It involved three radar installations in the 200-, 700-, and 3,000-mc bands. Simultaneous observations on shell bursts were to be made with all three equipments.

The Navy arranged with the Field Artillery Board to make these tests at Camp Davis, North Carolina. About 120 rounds of ammunition were available with 21 different fillers in the high explosive. The results were contrary to experience reported by British observers.

The SCR268 (200-mc) received echoes from all fillers at all ranges and worked about as well on pure TNT as on complicated fillers. The echo was similar to that previously observed.

The Navy FD (700-mc) followed the shell from the firing point, and observed a strong flash echo at the instant of burst, followed by a weaker persistent echo lasting from 15 to 30 sec. There were periodic variations of amplitude during the persistent echo. There was no observed agreement between filler and echo persistence. The flash echoes were better with some fillers than others. The exact details will be found in reference 24.

The MIT radar XT–1 (the 3,000-mc prototype of the SCR584) did not give useful echoes on any of the bursts at any range. There was considerable difficulty with this prototype equipment and there was no guarantee that the lack of echo from the bursts was a true phenomenon. The results with the XT–1 equipment were therefore inconclusive.

At this interesting stage of the experiments, Division 4 discontinued participation in the project.[1] Work was continued by the General Electric Company under contract to the Navy Department.

9.5 CONTROLLED-TRAJECTORY BOMBS

9.5.1 The Basic Problem

The development of a controlled-trajectory bomb having a glider-type attachment with adjustable control surfaces was initiated in Section E in January 1941. In December 1942, when Section E became Division 4, the project was transferred to Division 5. By the time of the transfer several models had been built and tested successfully in the field.

It appeared that improved accuracy of bombing, especially from high altitudes, could be obtained by using technical advances in radio, television, and aerodynamics to control the trajectories of bombs in flight.

The technical problems involved in controlling trajectories fell into three general categories as follows:

1. *Means for indicating to the bombardier the need of control.* Although there were many possible means for doing this, the most attractive solution appeared to be the use of television equipment in the bomb. The television picture would be transmitted by radio from the bomb to the bombardier, giving him the view ahead which he would have if he were actually riding on the bomb.

2. *Means of communication between the bombardier and the control mechanism.* The most practical solution to this problem appeared to be the use of a radio link.

3. *Method of applying forces to the bomb to modify its trajectory.* Although rocket control was suggested early and would have been possible, it was thought to involve additional and unnecessary complications. By far the most common and practical suggestion and the one that was adopted was to modify the aerodynamic forces on the bomb by changing the bomb's shape, that is, by turning a rudder which caused the bomb to assume a new orientation.

In addition the glider bomb itself would have to be developed. It would have to have the following characteristics:

1. *Good flight characteristics.* The problem of

[1] For additional information concerning this project, see references 25 through 35.

dynamic stability later proved to be the most serious aerodynamic problem and received foremost attention for nearly two years.

2. *Capacity for large explosive charge.* It was generally agreed that the cost of the control equipment would be such that nothing less than the equivalent of a standard general purpose 2,000-lb bomb should be considered and that, for many purposes, a larger weight would be desirable. It was decided early to take advantage of the large amount of work that had gone into the design of high-explosive bombs of the ordinary type by using a standard bomb as the component explosive part of the weapon.

3. *Ease of storage and handling properties.* The dimensions should be such that it could be carried on airplanes both while they were in flight and during take-off and landing operations. Although the use of towed glider bombs would have removed most size restrictions, it was felt that towed gliders would introduce many new and difficult aerodynamic problems relating to their stability and control.

9.5.2 Progress of Development

The development of a suitable aerodynamic structure for the glider bomb was the first problem to be undertaken. Scale models of a proposed structure were built and equipped with controls operated by a radio link. The first models were completely unstable, but, after extensive wind tunnel tests, a satisfactory aerodynamic design was achieved.

In parallel with the structural design, a television viewing set was developed. This weighed less than 100 lb and occupied about 2 cu ft. By June 1942, satisfactory field tests of glider bombs equipped with television sets were obtained.

Limitations of the television equipment to daylight operation were appreciated, and projects were initiated to remove this deficiency. One method was to provide suitable flares for illumination of the target at night, another was the development of radar bombing equipment. These projects were just getting well underway when, with the reorganization of NDRC in December 1942, further work was assigned to Division 5. Work completed under Division 4 (then Section E) direction is covered in detail in references 36, 37, and 38.[j]

[j] For information concerning the successful consummation of the project, reference is made to the reports of Division 5.

9.6 SUBSTITUTES FOR SILK IN POWDER BAGS[39,40,41]

The Armed Forces of the United States have used silk for making cartridge bags for large-caliber guns, largely because this fabric has greater resistance to progressive combustion and afterglow than do other common fabrics. The supply of silk was depleted with the beginning of the war with Japan, and a satisfactory silk substitute was sought, cotton receiving greatest attention because of its comparative abundance. Division 4 undertook work on the problem, utilizing textile experts at its central laboratories, the National Bureau of Standards.

Desired characteristics included flame resistance, adequate strength and resistance to deterioration, lack of smoldering and afterglow, as complete combustibility as practicable, and only moderate hygroscopicity.

Many materials with which cotton might be treated were known to have some of these characteristics, but were rejected because they were also known to lack others or because they were in critical supply.

Treated cotton fabrics were subjected to a number of tests to determine their flame and smolder resistance, hygroscopicity, resistance to aging and to deterioration by oxides of nitrogen. Weighted scores were compiled from these tests, greatest value being given to the characteristics considered most important.

One fabric was rated superior to silk, and two others were found nearly equal to silk. Of the 6 types tested, the material receiving the highest score was cotton treated with urea, hexamethylene tetramine, and ammonium dihydrogen phosphate. With a theoretically perfect material scored at 100, this treated cotton scored 73 as against a score of 71 for silk.

The material with the next highest score (69) was cotton treated with ammonium sulphate, urea, hexamethylene tetramine, and dibasic ammonium phosphate. A score of 68 was obtained when the cotton was treated with urea, hexamethylene tetramine, and ammonium ethyl-orthophosphate, the last a commercial product.

However, if the method of weighting is changed, one of the other treatments may be found preferable to that which received the highest rating with the weights given.[39]

[redacted]

BIBLIOGRAPHY

Numbers such as Div. 4-212-M1 indicate that the document listed has been microfilmed and that its title appears in the microfilm index printed in a separate volume. For access to the index volume and to the microfilm, consult the Army or Navy agency listed on the reverse of the half-title page.

Chapter 2

NDRC ARMOR AND ORDNANCE REPORTS

1. *The Photoelectric Fuze as of November 4, 1940,* L. R. Hafstad, NDRC Report A-1, November 1940. Div. 4-212-M1
2. *Measurements of Electric Fields near Airplanes in Flight,* E. J. Workman, NDRC Report A-7, June 1941. Div. 4-750-M1
3. *Studies of Acoustic Proximity Fuzes,* J. A. Reardon, NDRC Report A-12, July 1941. Div. 4-213-M1
4. *Acoustic Proximity Fuzes,* Richard K. Cook and W. C. Mock, Jr., NDRC Report A-23, Dec. 4, 1941. Div. 4-213-M2
5. *The Barotimer—A Barometrically Set Time Fuze,* S. K. Allison, W. P. Jesse, and T. J. O'Donnell, NDRC Report A-26, Jan. 1942. Div. 4-214-M1
6. *Radio Reporters for Proximity Fuze Testing,* A. V. Astin, NDRC Report A-53, May 1942. Div. 4-611-M1
7. *Continuously Adjustable Electric Time Fuze,* W. F. Westendorp, NDRC Report A-114, Nov. 11, 1942. Div. 4-215-M1
8. *Airbursts for Blast Bombs,* E. B. Wilson, Jr., NDRC Report A-322, April 1945. Div. 4-242.12-M4

MISCELLANEOUS REPORTS, DIVISION 4, NDRC

9. *An Adjustable Time Fuze Using Resistance-Capacitance Discharge Circuit,* C. A. Moreno, War Research Laboratory, University of Florida, Jan. 6, 1945. Div. 4-215-M2
10. *A Study of the Dielectric Properties of Dielectric Materials Made from Mixtures of Titanium Alloys,* D. C. Swanson, W. H. Beisler, and R. D. Walker, University of Florida, Sept. 2, 1945. Div. 4-239.3-M1
11. *Study of Condensers with Solid and Liquid Dielectrics,* H. L. Knowles and D. C. Swanson, University of Florida, Jan. 19, 1944. Div. 4-237-M2
12. *Interim Report, February 15 to March 7, 1945,* A. V. Astin to Dr. Alexander Ellett.

ARMY REPORTS

13. *The Optimum Point of Burst for a 500-lb GP Bomb Equipped with a Proximity Fuze,* Marston Morse, Wm. R. Transue, and Roy Kuebler, TDBS 7, Office of the Chief of Ordnance, Apr. 22, 1943.
14. *The Dependence of Optimum Height of Burst of Shells and Bombs upon Angle of Fall, Safety Angle, etc.,* Marston Morse, Wm. R. Transue, TDBS Report 41, Office of the Chief of Ordnance, Sept. 2, 1944.
15. *Optimum Height of Burst of Fragmentation Bombs and Effect with VT Fuzes,* Marston Morse, Wm. Transue, and M. H. Heins, TDBS Report 58, Office of the Chief of Ordnance, Apr. 3, 1945.
16. *Probable Advantages of VT Fuzes on 81-mm HE Mortar Shell M-56 and M-43A1,* Marston Morse, Wm. R. Transue, M. H. Heins, TDBS Report 60, Office of the Chief of Ordnance, Mar. 30, 1945.
17. *A Comparison of Damage Effect of Ground Bursts of 20-lb Bomb with an Air Burst of the 260-lb Bomb and of the 500-lb Bomb against Planes and Revetments,* TDBS Report 61, Office of the Chief of Ordnance, Apr. 24, 1945.
18. *Second Interim Report on Fuze, Bomb, T-50,* Report of the Army Air Forces Proving Ground Command on Project 4012C4712.82, Apr. 12, 1945.
19. *Supplemental Tests on Aircraft Rockets for Anti-Personnel Effects,* Report of the Army Air Forces Proving Ground Command on Project 4514C471.94, Sept. 4, 1945.

BRITISH REPORTS

20. *Trials with an M64 500-lb Bomb, Nose Initiated, Fuze No. T50 against Close Support Targets,* B. L. Welch, Appendix to Proceedings No. Q-2881, Ordnance Board, Dec. 13, 1944.

Chapter 3

1. *Notes on Conference of 12 August 1940 between Representatives of NDRC and BuOrd,* C. Hoover, Aug. 17, 1940. Div. 4-100-M1
2. *Initiation of Procurement of PE Fuzes for British 3-Inch UP Rocket,* Ordnance Committee Minutes 17426, Nov. 4, 1941.
3. *Development of Anti-Aircraft Fuzes for Rockets, Initiation of Project,* Ordnance Committee Minutes 18178, Apr. 24, 1942.
4. *Initiation of Development Project for T-50, T-51 and T-52 Fuzes,* Ordnance Committee Minutes 21117, July 17, 1943.
5. *The Photoelectric Proximity Fuze as of November 4, 1940,* L. R. Hafstad, NDRC, Armor and Ordnance Report 1. Div. 4-212-M1
6. *The Photoelectric Proximity Fuze,* L. R. Hafstad *et al.*, NDRC Armor and Ordnance Report A-20, Oct. 20, 1941. Div. 4-212.1-M1

Chapter 4

ARMOR AND ORDNANCE REPORTS DIVISION 4, NDRC

1. *The Photoelectric Proximity Fuze,* L. R. Hafstad *et al.*, NDRC Report A-20, Oct. 20, 1941. Div. 4-212.1-M1
   - 1a. *Ibid., General Considerations and Part I,* Section 5, pp. 30-39.
   - 1b. *Ibid., General Considerations and Part I,* Section 7, pp. 63-71.

1c. *Ibid., General Considerations and Part I,* Section 7, p. 65.
1d. *Ibid., Part I* (Continued), Section 30, p. 356.

REPORTS OF THE ORDNANCE DEVELOPMENT DIVISION OF THE NATIONAL BUREAU OF STANDARDS

2. *The Photoelectric Proximity Fuze for Rocket Projectiles,* S. H. Neddermeyer, unpublished report, Vol. 2, Sec. 1, pp. 14–17. Div. 4-212.2-M6
3. *Light Level Values for the North Sky,* R. Stair and W. E. Williams, Report OD-2-12, July 3, 1943. Div. 4-248-M4
4. *Estimates of Damage to Military Aircraft from a Head-on Burst of HVAR 5″ Rocket Shell as a Function of the Radius of Action of the Fuze,* B. M. Bennett, Report OD-OAG-54, Jan. 8, 1945. Div. 4-412.3-M4

MEMORANDA OF THE ORDNANCE DEVELOPMENT DIVISION OF THE NATIONAL BUREAU OF STANDARDS

5. *Measurement of Light Intensities at Altitudes up to 25,000 Feet,* Sept. 14, 1942. Div. 4-248-M3
6. *Pulse and Frequency Characteristics of MC-380 Amplifiers,* Memorandum to A. V. Astin from S. H. Neddermeyer, Mar. 31, 1943. Div. 4-238.221-M2

CONTRACTORS OF DIVISION 4, NDRC

7. *View Angle and Look-Forward Angle of MC-380A,* K. D. Smith, Bell Telephone Laboratories, Nov. 7, 1942. Div. 4-222.224-M2
8. *Probability that a 4½″ Rocket Fired from Astern Will Destroy a Twin Engine Bomber (Ju-88) as a Function of the Point of Burst,* OEMsr-618, Statistical Research Group to the Applied Mathematics Panel, Columbia University, AMP Report 21.1R, July 1944. Div. 4-412.3-M1

U. S. MILITARY PUBLICATIONS—ARMY ORDNANCE

9. *Fragment Distribution and Fragment Velocity of 4½″ HE Shell, M8,* N. A. Tolch, Report 344, Aberdeen Ballistics Laboratory.

Chapter 5

ARMOR AND ORDNANCE REPORTS, NDRC

1. *The Photoelectric Proximity Fuze, General Considerations* and *Part I,* Volumes I and II, L. R. Hafstad *et al.,* NDRC Report A-20, Dec. 20, 1941. Div. 4-212.1-M1
2. *The Status of the Photoelectric Proximity Fuze for Rockets on March 13, 1942,* NDRC Report A-44, Pilot Photoelectric Fuze Development Group at the National Bureau of Standards, Mar. 16, 1942. Div. 4-212.2-M2

REPORTS OF THE ORDNANCE DEVELOPMENT DIVISION OF THE NATIONAL BUREAU OF STANDARDS

3. *The Photoelectric Proximity Fuze for Rocket Projectiles,* J. E. Henderson, S. H. Neddermeyer, *et al.,* unpublished report, Vols. I and II, 1942. Div. 4-212.2-M6
4. *Testing of Pentodes,* R. A. Becker, Apr. 28, 1942. Div. 4-231.4-M1
5. *Gas Currents and Input Impedance of HY145YT,* R. A. Becker, Aug. 1, 1942. Div. 4-231.4-M2
6. *Report of Centrifuging of 24 HY-145-YT Pentodes to 2000 g,* R. A. Becker and C. Ravitsky, Sept. 19, 1942. Div. 4-231.4-M3
7. *Progress Report on a Double Photocell Photoelectric Unit,* R. Hofstadter, Nov. 11, 1942. Div. 4-231.51-M1
8. *Progress Report on Operation of a Single-Stage Unit without a B Battery,* R. A. Becker and C. Ravitsky, Nov. 11, 1942. Div. 4-232.1-M4
9. *Progress Report #2 on Condenser-Driven Single-Stage Photoelectric Unit,* R. A. Becker, C. Ravitsky, and D. Feldman, Dec. 14, 1942. Div. 4-212.3-M2
10. *Report of Test of 100 Assembled MC-380B Fuzes for Conformity to the September 30, 1942 Issue of MC-380 Fuze Specifications (NDRC),* Joseph E. Henderson, Dec. 21, 1942. Div. 4-222.224-M3
11. *Effect of Light and Heat on Photocell Sensitivity,* W. E. Williams, Jr., Memorandum Report 3-P, Jan. 15, 1943. Div. 4-231.5-M4
12. *Fuze, Rocket, PEP Condenser-Powered, Westinghouse, N Range, Corncake, March 4 and 5, 1943,* R. Vorkink, Memorandum Report 108-T, Mar. 23, 1943. Div. 4-222.222-M4
13. *Test of Reserve Batteries at Corncake, March 10, 1943,* A. V. Astin and A. W. Spinks, Memorandum Report 117-T, March 24, 1943. Div. 4-232.1-M5
14. *Pulse and Frequency Characteristics of MC-380 Amplifiers,* Seth H. Neddermeyer, Mar. 31, 1943. Div. 4-238.221-M2
15. *Heater Cathode Pentodes,* preliminary report, D. Feldman, Apr. 5, 1943. Div. 4-231.4-M9
16. *Use of Polymerized Tung Oil for Potting MC-380 and MC-382 Fuzes,* C. Brunetti and P. J. Franklin, Apr. 29, 1943. Div. 4-239.1-M1
17. *Preliminary Report on Adaptation of the Photoelectric Fuze to a Generator Power Supply,* J. F. Streib, D. Feldman, and W. E. Armstrong, Memorandum Report 29-P, Apr. 30, 1943. Div. 4-232.2-M5
18. *Small G. E. Photocells Received May 22, 1943,* W. E. Williams, Jr., Memorandum Report 34-P, June 7, 1943. Div. 4-231.5-M16
19. *Frequency Characteristics of Variations of MC-380 Amplifier,* R. Stair, Seymour Golden, and Paul Miller, Report OD-2-1, June 8, 1943. Div. 4-238.221-M3
20. *Matching Photocells and Non-Linear Load Resistors in the MC-380 Circuit,* J. G. Hoffman and R. F. Morrison, Memorandum Report 32-P, June 8, 1943. Div. 4-238.41-M4
21. *Spectral Response of Types GL-516 and GL-564*

General Electric Photocells, R. Stair and W. E. Williams, Jr., Report OD-2-5, June 19, 1943. Div. 4-231.5-M18

22. *Light Level Values for the North Sky,* R. Stair and W. E. Williams, Jr., Report OD-2-12, July 3, 1943. Div. 4-248-M4
23. *Circuit Parameters Suitable for Use with General Electric Pentodes in the MC-380 Unit,* R. Stair and Seymour Golden, Report OD-2-11, July 8, 1943. Div. 4-231.4-M11
24. *Sun Firing Properties of M-2 Fuzes,* F. L. Mohler, Report OD-2-1, July 8, 1943. Div. 4-222.224-M18
25. *Use of the M-2 Fuze,* A. V. Astin, Report OD-2-17, July 15, 1943. Div. 4-222.224-M20
26. *Progress Report on Double Lenses,* F. L. Mohler, July 17, 1943. Div. 4-234-M4
27. *Potential Substitutes for Tung Oil and Ceresin Wax,* P. J. Franklin, Report OD-5-42, July 19, 1943. Div. 4-239.1-M2
28. *Dielectric Constant and Power Factor Loss of Some Potting Materials,* P. J. Franklin, Aug. 3, 1943. Div. 4-239.1-M3
29. *Impedance of the MC-380 Input Circuit as a Function of Photocell Sensitivity,* J. G. Hoffman and R. F. Morrison, Report OD-2-16, Aug. 12, 1943. Div. 4-238.41-M5
30. *Leakage of Gas into General Electric GL-564 Photocells,* W. E. Williams, Jr., Report OD-2-17, Aug. 28, 1943. Div. 4-231.5-M19
31. *A Sunproof Modification of the MC-380 Fuze,* J. G. Hoffman, R. F. Morrison, and G. L. Scillian, Report OD-2-21, Sept. 4, 1943. Div. 4-247-M4
32. *Results of Tests on 400 R.C.A. Photocells, Type 936, Received June 15, 1943,* W. E. Williams, Jr., Report OD-2-19, Sept. 6, 1943. Div. 4-231.5-M20
33. *Results of Tests on 2000 G. E. Photocells, Type IP24, Received July 8 and 17, 1943,* W. E. Williams, Jr., Report OD-2-20, Sept. 7, 1943. Div. 4-231.5-M21
34. *Revision of the MC-380 Circuit,* J. G. Hoffman, R. Stair, and A. Orden, Report OD-2-2, Oct. 1, 1943. Div. 4-238.1-M2
35. *Laboratory and Field Tests on RPEB-2 Fuze,* A. V. Astin and A. Orden, Report OD-2-3, Oct. 23, 1943. Div. 4-222.225-M4
36. *Probability of Sun Firing of M-2 Fuzes,* A. V. Astin, Report OD-2-4, Nov. 15, 1943. Div. 4-222.224-M25
37. *A Further Study of the Sunproof Modifications of the MC-380 Fuze,* G. L. Scillian, R. F. Morrison, and J. G. Hoffman, Report OD-2-5, Nov. 22, 1943. Div. 4-247-M5

MEMORANDA OF THE ORDNANCE DEVELOPMENT DIVISION OF THE NATIONAL BUREAU OF STANDARDS

38. *Varistor Thyrite Material,* R. A. Becker, Mar. 28, 1942. Div. 4-236.1-M1
39. *Night PE Fuze,* J. F. Streib, Apr. 16, 1942. Div. 4-248-M1
40. *Preliminary Test on Night Operation of Photoelectric Fuze, (W.E. Model AR) with Light Source Carried by Projectile, by Means of Falling Spheres,* J. F. Streib, Apr. 17, 1942. Div. 4-222.23-M1
41. *Development of Thyrite for Special Use,* R. Hofstadter, July 6, 1942. Div. 4-236.1-M2
42. *Photocell-Varistor Combinations,* R. Hofstadter and R. F. Morrison, Sept. 9, 1942. Div. 4-238.41-M1
43. *Effect of Variation of Grid Resistor on Initial Input Impedance and Performance of One-Stage P.E. Unit,* R. A. Becker and David Feldman, Sept. 29, 1942. Div. 4-236-M1
44. *Double Input Circuits,* J. F. Streib, Nov. 11, 1942. Div. 4-238.43-M1
45. *Theoretical Voltage Output from a Double Photocell Circuit,* R. Hofstadter, Nov. 12, 1942. Div. 4-231.51-M2
46. *Double Lenses,* F. L. Mohler, Nov. 13, 1942. Div. 4-234-M4
47. *Sun Firing,* W. E. Armstrong, Nov. 19, 1942. Div. 4-247-M1
48. *Double Photocell Circuit,* T. M. Marion, Dec. 11, 1942. Div. 4-231.51-M3
49. *Operation of Parallel, Double Photocell Circuit,* T. M. Marion, Dec. 12, 1942. Div. 4-231.51-M4
50. *Paint Formulation for Methyl Methacrylate Resins,* P. J. Franklin, Jan. 18, 1943. Div. 4-234.1-M1
51. *Zero Stage Units,* R. Hofstadter, Jan. 30, 1943. Div. 4-238.42-M1
52. *Zero Stage Units,* R. Hofstadter, Feb. 18, 1943. Div. 4-238.42-M2
53. *Tube Constants of Pentodes Used in the MC-380 and Condenser Unit Circuits,* D. Feldman, Feb. 26, 1943. Div. 4-231.4-M8
54. *Uniformity of Fuzes Measured with Half the Lens Uniformly Illuminated,* F. L. Mohler, Mar. 6, 1943. Div. 4-222.224-M6
55. *Shift in Frequency Transmissions of MC-380,* S. Golden, Mar. 15, 1943. Div. 4-238.1-M1
56. *Photothyratrons,* R. F. Morrison, Jr., Mar. 17, 1943. Div. 4-231.1-M6
57. *The Use of High Sensitivity Photocells,* J. G. Hoffman, Mar. 19, 1943. Div. 4-238.4-M1
58. *Gas-Filled R.C.A. 936 Photocells,* T. M. Marion, Mar. 29, 1943. Div. 4-231.5-M10
59. *The Balanced Double Input Circuit,* J. F. Streib, Apr. 1, 1943. Div. 4-238.43-M2
60. *Additional Remarks on Series Double Input Circuit,* J. F. Streib, Apr. 5, 1943. Div. 4-238.43-M3
61. *Paint to Minimize Crazing,* P. J. Franklin, Apr. 7, 1943. Div. 4-234.1-M2
62. *Status of Condenser Unit,* A. V. Astin, Apr. 12, 1943. Div. 4-237-M1
63. *Recommendation of Non-Crazing Surface Coating for Lucite,* P. J. Franklin, Apr. 12, 1943. Div. 4-234.1-M3
64. *Status of Reserve Batteries,* A. V. Astin, Apr. 17, 1943. Div. 4-232.1-M6
65. *The Use of High Sensitivity Photocells in the MC-380 Unit,* J. G. Hoffman, Apr. 19, 1943. Div. 4-238.4-M1
66. *Results of Electrical and Mechanical Tests on 95 G. E. Photocells Received April 14, 1943,* W. E. Williams, Jr., Apr. 19, 1943. Div. 4-231.5-M12

67. *SA-804 Slow Cooling Pentodes,* D. Feldman, Apr. 22, 1943. Div. 4-231.4-M10
68. *Effect of Light Level on the Threshold of MC-380 Units,* C. Ravitsky, May 10, 1943. Div. 4-222.224-M10
69. *Radium Treatment of Neon Lamps,* C. Brunetti, May 13, 1943. Div. 4-231.6-M2
70. *High Sensitivity Photocells,* A. V. Astin, June 10, 1943. Div. 4-231.5-M17
71. *A Method for Preventing Sunfiring,* T. M. Marion, July 8, 1943. Div. 4-247-M2
72. *Test of Willard Reserve A Cell,* A. Orden, July 29, 1943. Div. 4-232.1-M7
73. *Notes of Double PE Cell Input Circuit,* J. G. Hoffman, Aug. 12, 1943. Div. 4-231.51-M5
74. *Sun Transients in the MC-380 Amplifier Circuit,* R. F. Morrison, Jr., Sept. 10, 1943. Div. 4-238.221-M4
75. *RPEB-2's Fired at Blossom Point on September 9, 1943,* A. Orden, Sept. 11, 1943. Div. 4-222.225-M1

SPECIFICATIONS OF THE ORDNANCE DIVISION OF THE NATIONAL BUREAU OF STANDARDS

76. *Manufacturing Specification for 50 Units to be Manufactured by Westinghouse,* S. H. Neddermeyer, June 6, 1942. Div. 4-222.23-M2
77. *Specification for a Powder Train Interrupter and Electric Switch for Fuzes for 4.5 Projectile,* W. B. McLean, Aug. 31, 1942. Div. 4-238.511-M2
78. *Proposed Specification for Manufacture and Inspection of a Battery for Section E, Division A, NDRC,* Sept. 1, 1942. Div. 4-232.1-M3
79. *Test Specifications for Varistors or Thyrite Units, Draft 4,* Robert Hofstadter, Sept. 29, 1942. Div. 4-236.1-M4
80. *Specification for Manufacture and Testing of SA-780A Triode, SA-781A Pentode, and SA-782B Thyratron,* C. Brunetti, Sept. 30, 1942. Div. 4-231-M1
81. *Specification for HY-145-ZT Pentodes for Photoelectric Proximity Fuzes,* R. A. Becker, Sept. 30, 1942. Div. 4-231.4-M5
82. *Proposed Specification for Manufacture and Inspection of GY-2 Thyratron Tube,* Sept. 30, 1942. Div. 4-231.1-M2
83. *Tentative Test Specification of Photocell RCA 936 (Formerly C-7063), Draft 5,* Sept. 30, 1942. Div. 4-231.5-M1
84. *Specification for Manufacture and Testing of a Photoelectric Proximity Fuze for Rocket Projectiles,* Sept. 30, 1942. Div. 4-212.2-M3
85. *MC-380 Mechanical Specifications,* C. B. Crane, Nov. 2, 1942. Div. 4-222.224-M1
86. *Specification for Manufacture and Inspection of Microthyratron Tube,* Robert Hofstadter, Nov. 6, 1942. Div. 4-231.1-M3
87. *Specifications or Standards for Inspection of BR Lenses,* F. L. Mohler, Nov. 30, 1942. Div. 4-234-M7
88. *Proposed Specification for Acceptance Gages to be Used with M-2 and M-3 Fuze Components,* C. B. Crane, Dec. 3, 1942. Div. 4-619-M1
89. *Suggested Form of Specifications for Manufacture and Inspection of a Neon Tube,* Dec. 16, 1942. Div. 4-231.6-M1
90. *Tentative Specification for Field Test Set IE-28,* A. S. Clarke, Dec. 31, 1942. Div. 4-222.223-M2
91. *Photocell Specifications; Gas Multiplication Ratio,* J. F. Streib, Mar. 5, 1943. Div. 4-231.5-M6
92. *Photocell Specifications; Tinning Tabs,* J. F. Streib, Mar. 8, 1943. Div. 4-231.5-M9
93. *Photocell Specifications; Flat Region on Seat,* J. F. Streib, Mar. 8, 1943. Div. 4-231.5-M8
94. *Photocell Specifications; Uniformity,* J. F. Streib, Mar. 8, 1943. Div. 4-231.5-M7
95. *Specification for Electron Tube NN1; Description: Photocell,* June 1, 1943. Div. 4-231.5-M15

REPORTS AND MEMORANDA OF CONTRACTORS OF DIVISION 4, NDRC

96. *PERF Apparatus, Model BR, as Made by Western Electric Company, Inc.,* Hawthorne Works, Chicago, Ill., Specifications for manufacture, X-61637, Issue 1, Systems Development Department, Bell Telephone Laboratories, Jan. 29, 1942. Div. 4-212.2-M1
97. *Manufacturing Testing Requirements for Parts and Assemblies Used in PERF Apparatus,* Western Electric Company, Model BR (X-61637); Specification for testing, X61636, Issue 4, Systems Development Department, Bell Telephone Laboratories, Mar. 9, 1942. Div. 4-222.226-M1
98. *Engineering Memorandum of Trip to Bureau of Standards and Baltimore Radio Division, August 3 and 4, 1942,* E. K. Clark, Mansfield Works, Westinghouse Electric and Manufacturing Company, Aug. 6, 1942. Div. 4-210-M1
99. *Memorandum of Meeting in Washington, August 4,* W. J. Russell, Mansfield Works, Westinghouse Electric and Manufacturing Company, Aug. 6, 1942. Div. 4-212.3-M1
100. *Request for Permission to Make a Circuit Wiring Change in MC-380-A Fuze Head, Case 23236,* J. M. West, Bell Telephone Laboratories, Oct. 26, 1942. Div. 4-238.221-M1
101. *Memorandum for Record, Case 23826,* W. O. Baker, Bell Telephone Laboratories, Nov. 27, 1942. Div. 4-234-M5
102. *Memorandum for Record, Case 23854,* W. O. Baker, J. H. Heiss, Jr., and N. R. Pape, Bell Telephone Laboratories, Nov. 28, 1942. Div. 4-234-M6
103. *Report on Special Phototube Investigation in Research Laboratory, June 1, 1942-January 31, 1943,* S. Dushman, Research Laboratory, General Electric Company, Schenectady, N. Y., Feb. 2, 1943. Div. 4-231.5-M5
104. *Final Report on Photoelectric Fuzes,* submitted by the Bell Telephone Laboratories for the Western Electric Company, New York, J. F. Wentz, Mar. 1, 1943. Div. 4-212.2-M4
105. *Progress in Photo-Tube Work,* Interim Report No. 171, March 2 to April 8, 1943, S. Dushman, OEMsr-611, Research Laboratory, General Electric Company, Schenectady, N. Y., Apr. 8, 1943. Div. 4-231.5-M11

[redacted]

106. *Weekly Progress Report for Week Ending May 29, 1943,* S. Dushman, OEMsr–611, Research Laboratory, General Electric Company, Schenectady, N. Y., May 29, 1943. Div. 4–231.5–M14
107. *Proximity Fuzes, J. F. Wentz,* final report submitted by the Bell Telephone Laboratories for the Western Electric Company, New York, under Contract OEMsr–500, July 31, 1943. Div. 4–212.2–M5
108. *Final Technical Report on Generator-Powered Proximity Fuzes for Bombs,* report submitted by the Bell Telephone Laboratories under Contract OEMsr–905, Mar. 24, 1944. Div. 4–211.21–M5
109. *Report to Division 4, National Defense Research Committee on Contract OEMsr–1003,* A. M. Glover and A. R. Moore, Report 1003–1, Radio Corporation of America, Lancaster, Pa., Oct. 23, 1944. Div. 4–231–M3

U. S. ARMY PUBLICATIONS

110. *Nose MC–380–( ). Specification No. 371–2031,* Camp Evans Signal Laboratory, Camp Evans, Belmar, N. J., Jan. 27, 1943.
111. *Proof Firing Test Formula for Specification Nos. 371–2027 and 371–2031,* Feb. 24, 1943.
112. *TM11–2502. Test Equipment IE–28,* War Department Technical Manual, Aug. 31, 1943.
113. *TB 9X–94. Fuze, Rocket, P.D., T4 and T5,* War Department Training Bulletin, Dec. 1944.

UNCLASSIFIED PUBLICATIONS

114. *Varistors.* A group of articles reprinted from Bell Laboratories *Record.*
115. *Thyrite: A G.E. Resistance Material,* General Electric Company.

Chapter 6

ARMOR AND ORDNANCE REPORTS OF DIVISION 4, NDRC

1. *The Photoelectric Proximity Fuze,* L. R. Hafstad *et al.,* NDRC Report A–20, Part I (Continued), Section 19, Oct. 20, 1941, pp. 206–208. Div. 4–212.1–M1

REPORTS OF THE ORDNANCE DEVELOPMENT DIVISION OF THE NATIONAL BUREAU OF STANDARDS

2. *The Photoelectric Proximity Fuze for Rocket Projectiles,* S. H. Neddermeyer, unpublished report, Vol. 2, Section 7, pp. 108–118. Div. 4–212.2–M6
2a. *Ibid.,* p. 108.
3. *Preliminary Proposal for a System of Matching Non-Linear Load Resistors to Photocell,* J. G. Hoffman, Report 25–P, Apr. 20, 1943. Div. 4–238.41–M2
4. *Proposed Method of Matching Non-Linear Load Resistors to Photocell,* J. G. Hoffman, Report 27-P, May 4, 1943. Div. 4–238.41–M3

MEMORANDA OF THE ORDNANCE DEVELOPMENT DIVISION OF THE NATIONAL BUREAU OF STANDARDS

5. *Description of Photocell Testing Apparatus and Procedure,* Memorandum to S. H. Neddermeyer from J. F. Streib, Mar. 26, 1942. Div. 4–238.44–M1
6. *Gas Currents and Input Impedance of HY–145–YT,* Memorandum to J. E. Henderson from R. A. Becker, Aug. 1, 1942. Div. 4–231.4–M2
7. *Report on Light Measurements Made on the Altitude Flights of August 23 and 28, 1942,* J. G. Hoffman, Aug. 28, 1942. Div. 4–248–M2
8. *Resolving Power of Westinghouse Lenses and Position of Photocell; Effective Aperture,* Memorandum to J. E. Henderson from F. L. Mohler, Sept. 11, 1942. Div. 4–234–M1
9. *Varistor Behavior at Different Temperatures,* Memorandum to J. E. Henderson from R. Hofstadter, W. C. Armstrong, J. Heyman, and R. F. Morrison, Sept. 14, 1942. Div. 4–236.1–M3
10. *Inspection of Lenses, etc.,* Memorandum to J. E. Henderson from F. L. Mohler, Sept. 18, 1942. Div. 4–234–M2
11. *Suggested Procedure for Measuring Photocell Current in Testing Sensitivity of the Optical-Photocell System of PE Fuze without Disassembling,* Memorandum to F. L. Mohler from J. F. Streib, Sept. 26, 1942. Div. 4–238.44–M2
12. *Effect of Variation of Grid Resistor on Initial Input Impedance and Performance of One-Stage PE Unit,* Memorandum to J. E. Henderson from R. A. Becker and D. Feldman, Sept. 29, 1942. Div. 4–236–M1
13. *A Rectified AC Method of Measuring Photocell Characteristics and Tests on Some Westinghouse Lenses,* Memorandum to J. E. Henderson from F. L. Mohler, Oct. 12, 1942. Div. 4–238.44–M3
14. *Recommendations for Quality Inspection of Lenses in the Manufacturing Plant,* F. L. Mohler, Oct. 20, 1942. Div. 4–234–M3
15. *Photocell Inspection,* Memorandum to J. E. Henderson from J. F. Streib, Oct. 22, 1942. Div. 4–238.44–M4
16. *Input Impedances of Hytron 145–ZT Pentodes,* Memorandum to R. A. Becker from D. Feldman, Nov. 16, 1942. Div. 4–231.4–M6
17. *Humidity Tests on Varistor Specifications,* Memorandum to A. Ellett from R. Hofstadter, Nov. 17, 1942. Div. 4–236.1–M5
18. *Testing of HY–145–ZT Pentodes,* Nov. 27, 1942. Div. 4–231.4–M7
19. *Twenty-Four Hour Humidity Test on Thyrite Units and Varistors,* Memorandum to R. Hofstadter from R. F. Morrison, Dec. 2, 1942. Div. 4–236.1–M6
20. *Results of Tests on 44 G.E. Photocells to Determine the Effect of Change of Illumination on Sensitivity,* Memorandum to J. E. Henderson and J. F. Streib from W. E. Williams, Jan. 7, 1943. Div. 4–231.5–M2
21. *Results of Tests on 30 G.E. Photocells to Determine the Effect of Change of Illumination on Sensitivity,*

Memorandum to J. E. Henderson and J. F. Streib from W. E. Williams, Jan. 9, 1943. Div. 4–231.5–M3
22. *Repeated Surges of Thyratrons,* Memorandum to J. E. Henderson from R. F. Morrison, Feb. 24, 1943. Div. 4–231.1–M5
23. *Measurement of Light Thresholds of MC–380 PE Units,* Memorandum to J. E. Henderson from S. H. Neddermeyer, Mar. 13, 1943. Div. 4–222.224–M7
24. *Preliminary Proposal for a System of Matching Non-Linear Load Resistor to Photocell,* Memorandum to J. G. Hoffman from R. F. Morrison, Apr. 12, 1943.
25. *Matching Photocells and Non-Linear Load Resistors in the MC–380 Circuit,* Memorandum to A. V. Astin from J. G. Hoffman, May 3, 1943.
26. *Matching Photocells and Non-Linear Load Resistors in the MC–380 Circuit,* Memorandum to A. V. Astin from J. G. Hoffman, June 8, 1943. Div. 4–238.41–M4
27. *A Preliminary Report on Sun Firing of the 380 Fuze as Measured on the Yaw Machine,* Memorandum to A. V. Astin from F. L. Mohler, July 8, 1943. Div. 4–222.224–M19

SPECIFICATIONS

28. *Specifications for the HY–145–ZT Pentodes for Photoelectric Proximity Fuze,* Section E, Division A, NDRC. Sept. 30, 1942. Div. 4–231.4–M5
29. *Specifications for Electron Tube NN1: Description; Photocell,* June 1, 1943. Div. 4–231.5–M15

DRAWINGS OF THE ORDNANCE DEVELOPMENT DIVISION OF THE NATIONAL BUREAU OF STANDARDS

30. *NBS Drawing No. 3012: Standard PEC Mount.* Div. 4–231.52–M1
31. *NBS Drawing No. 3013: Shutter and Baffle.* Div. 4–231.52–M2
32. *NBS Drawing No. 3014: Test Cell Mount Assembly.* Div. 4–231.52–M3
33. *NBS Drawing No. 3015: Test Cell Mount Details.* Div. 4–231.52–M4
34. *NBS Drawing No. 3016: Test Cell Mount Details.* Div. 4–231.52–M4
35. *NBS Drawing No. 3017: Lamp Socket.* Div. 4–231.52–M5
36. *NBS Drawing No. 3018: PEC Test Unit Cabinet.* Div. 4–231.52–M6
37. *NBS Drawing No. 3019: PEC Test Unit Cabinet.* Div. 4–231.52–M7
38. *NBS Drawing No. A3164: Light Angle Device Wiring Diagram.* Div. 4–231.52–M8
39. *NBS Drawing No. L5017: Photocell.* Div. 4–231.5–M13

Chapter 7

ARMOR AND ORDNANCE REPORTS OF DIVISION 4, NDRC

1. *The Photoelectric Proximity Fuze,* L. R. Hafstad *et al.,* NDRC Report A-20, Part I (Continued), Oct. 20, 1941. Div. 4–212.1–M1
1a. *Ibid.,* pp. 275–306.
1b. *Ibid.,* pp. 307–355.
2. *Radio Reporters for Proximity Fuze Testing,* A. V. Astin, NDRC Report A–53, May 21, 1942. Div. 4–611–M1

REPORTS OF THE ORDNANCE DEVELOPMENT DIVISION OF THE NATIONAL BUREAU OF STANDARDS

3. *The Photoelectric Proximity Fuze for Rocket Projectiles,* S. H. Neddermeyer, unpublished report, Vol. 2, Section 8, pp. 119–132. Div. 4–212.2–M6
4. *Analysis of Proving Ground Data on Experimental Photoelectric Fuzes Fired at Fort Fisher,* unpublished report.
5. *PE Range Testing at Corncake with Reporters,* A. V. Astin, Memorandum Report P. G. 209, Aug. 21, 1942. Div. 4–222.221–M2
6. *PE Range Tests with Radio Reporters,* A. V. Astin, Memorandum Report P. G. 244, Sept. 1, 1942. Div. 4–222.221–M3
7. *PE Range Tests with Reporters,* A. V. Astin, Memorandum Report P. G. 303, Sept. 25, 1942. Div. 4–222.221–M4
8. *Photocell Current Measurements with Reporters,* A. V. Astin, Memorandum Report P. G. 305, Sept. 26, 1942. Div. 4–222.221–M5
9. *Proposed Proof Range for M–2 and M–3 Fuzes at Aberdeen Proving Center,* H. Diamond, Memorandum Report 1–M, Dec. 29, 1942. Div. 4–222.223–M1
10. *Range Testing at Blossom Point for PE Fuzes,* A. V. Astin, Report 14–T, Jan. 5, 1943. Div. 4–222.224–M4
11. *Yaw Reporter Test,* L. C. Miller, Report 401–T, Aug. 9, 1943. Div. 4–222.221–M7
12. *Laboratory and Field Tests on RPEB–2 Fuze,* A. V. Astin and A. Orden, Report OD–2–3, Oct. 23, 1943. Div. 4–222.225–M4
13. *Report of Tests with Reporters at Aberdeen,* Memorandum from A. V. Astin, Nov. 29, 1941. Div. 4–222.221–M1
14. *Range Firing of Radio Reporters and PE Fuzes to Determine Suitability of Range for Testing PE Fuzes at Blossom Point, Md.,* Memorandum to J. E. Henderson from J. F. Streib, Dec. 16, 1942. Div. 4–222.221–M6
15. *Targets for MC–380 Units,* Memorandum to H. Diamond from A. V. Astin, July 3, 1943. Div. 4–618–M3

Chapter 8

ARMOR AND ORDNANCE REPORTS OF DIVISION 4, NDRC

1. *The Photoelectric Proximity Fuze,* L. R. Hafstad *et al.,* NDRC Report A–20, Part I (Continued), Section 28, Oct. 20, 1941. Div. 4–212.1–M1

[redacted]

REPORTS OF THE ORDNANCE DEVELOPMENT DIVISION OF THE NATIONAL BUREAU OF STANDARDS

2. *The Photoelectric Proximity Fuze for Rocket Projectiles,* S. H. Neddermeyer, unpublished report, Volume 1. Div. 4-212.2-M6
3. *PE Fuzes for 4½ PP Rocket, Condenser B Supply, Report on Target Function, 12 Rounds, Corncake, December 31, 1942,* T. N. White, Report 19-T, Jan. 12, 1943. Div. 4-222.222-M2
4. *Frequency of Yaw of Budd 4½-inch Rockets Fired from a Plane,* T. B. Godfrey, Report 47-T, Feb. 11, 1943.
5. *Fuze, Rocket, PED Condenser-Powered Westinghouse, N Range, Corncake,* March 4 and 5, 1943, R. Vorkink, Report 108-T, Mar. 23, 1943. Div. 4-222.222-M4
6. *Range Test at Blossom Point with PEP Rocket Fuzes,* L. C. Miller, Report 116-T, Mar. 24, 1943. Div. 4-222.222-M5
7. *Fuze MC-380 Wurlitzer, Rejects with Changed Coupling Condensers, Target Function Test,* T. N. White, Report 155-T, Apr. 12, 1943 Div. 4-618-M1
8. *Fuze MC-380 B (Westinghouse) with Pentode Plate and Screen Resistor Changes,* L. C. Miller, Report 167-T, Apr. 20, 1943. Div. 4-222.224-M8
9. *Evaluations of Ground-Approach Functions, PEP and RRP Fuzes, Fort Bragg, April 14 and 15, 1943,* J. L. Thomas and T. N. White, Report 180-T, Apr. 23, 1943. Div. 4-241-M1
10. *Test of Special MC-380 Fuzes—Westinghouse in Connection with the Problem of Gassy Pentodes,* L. C. Miller, Report 232-T, May 10, 1943. Div. 4-222.224-M11
11. *Test of Special MC-380 Western Electric Fuzes (Veazie Circuit) in Connection with the Problem of Gassy Pentodes,* L. C. Miller, Report 244-T, May 19, 1943. Div. 4-222.224-M12
12. *Test of Special MC-380 Western Electric Fuzes in Connection with the Problem of Gassy Pentodes,* L. C. Miller, Report 271-T, June 3, 1943. Div. 4-222.224-M13
13. *Experimental MC-380 Fuzes Fired against Small Flat Target, North Range, Corncake, May 27, 28, 29, 30, 1943,* T. N. White and A. V. Astin, Report 337-T, July 7, 1943. Div. 4-222.224-M17
14. *Fuze PEP-M-2, MC-380-NBS Special Modified Fuzes, Test for Target Function,* R. Vorkink, Report 346-T, July 5, 1943. Div. 4-618-M4
15. *Fuze PEP-M-2, MC-380-NBS Special Rejects, Test for Target Function,* R. Vorkink, Report 347-T, July 6, 1943. Div. 4-618-M5
16. *Fuze PEP-M-2, MC-380-Westinghouse Special Microphonic Rejects,* R. Vorkink, Report 348-T, July 7, 1943. Div. 4-222.226-M2
17. *Test on Microphonic MC-380 Fuzes,* D. C. Friedman, Report 378-T, July 22, 1943. Div. 4-222.224-M21
18. *Test of Five BTL BPEG Fuzes,* L. C. Miller, Report 387-T, July 24, 1943. Div. 4-222.21-M2
19. *Sun Firing of Photoelectric Fuzes on Rockets,* H. F. Stimson, Report 392-T, Sept. 3, 1943. Div. 4-247-M3
20. *Yaw Reporter Test,* L. C. Miller, Report 401-T, Aug. 9, 1943. Div. 4-222.221-M7
21. *Ten BTL BPEG Fuzes, Tests for Target Functions and Self-Destruction,* R. Vorkink, Report 410-T, Aug. 12, 1943. Div. 4-222.21-M3
22. *Test of Special MC-380 Fuzes Designed to Prevent Sunfiring,* L. C. Miller, Report 428-T, Sept. 4, 1943. Div. 4-222.224-M23
23. *Analysis of Field Tests of Condenser-Powered PE Units, Fort Fisher, March 3, 4, and 5, 1943,* S. H. Neddermeyer, Report 16-P, Mar. 6, 1943. Div. 4-222.222-M3
24. *Tests of Photoelectric Fuzes on Rotating 4½-inch Budd Rockets, March 1, 1943,* S. H. Neddermeyer, Report 17-P, Mar. 26, 1943. Div. 4-222.23-M4
25. *Uniformity of MC-380 Fuze Noses Measured with Half the Lens Uniformly Illuminated,* F. L. Mohler, Report 18-P, Mar. 26, 1943. Div. 4-222.224-M6
26. *Ground Firing Tests of MC-380 Fuzes at Fort Bragg, April 14-15, 1943,* A. V. Astin, Report 22-P, Apr. 22, 1943. Div. 4-222.224-M9
27. *Test of Bomb Mounted MC-380 Fuzes at Aberdeen,* A. V. Astin, Report 23-P, Apr. 23, 1943. Div. 4-222.21-M1
28. *Tests of MC-380 Units with Photocells Rejected for Excessive Fragments,* A. V. Astin and W. E. Williams, Report 38-P, June 29, 1943. Div. 4-222.224-M15
29. *Triggering of MC-380's by Poles on the North Range,* A. Orden, Report 39-P, July 3, 1943. Div. 4-222.224-M16
30. *Use of MC-380's on AN-M-30 at Eglin Field, July 26 through July 30, 1943,* A. V. Astin, Report 42-P, Aug. 5, 1943. Div. 4-222.224-M22
31. *Target Test of 67 RPEB-2 Fuzes with 20 MC-380 Controls (Using 4 Target Array), at Blossom Point,* R. Vorkink, Report OD-1-9, Sept. 20, 1943. Div. 4-222.225-M2
32. *Salvo Firing in Search of Sympathetic Functioning,* F. R. Kotter and T. N. White, Report OD-1-15, Sept. 25, 1943. Div. 4-245-M1
33. *Target Test of 79 RPEB with 30 MC-380 Controls Using 4 Target Array at Blossom Point,* R. Vorkink, Report OD-1-25, Oct. 14, 1943. Div. 4-222.225-M3
34. *Test of 25 Sun-Proofed MC-380 Fuzes with 50 Regular MC-380 Controls, Fired over Ground,* R. Vorkink, Report OD-1-36, Nov. 8, 1943. Div. 4-222.224-M24
35. *Effect of Rocket Spin upon the Performance of VT Fuzes, T-4, T-5, T-6,* T. B. Godfrey, Report OD-1-668, Mar. 13, 1945.
36. *Sun Firing Properties of M-2 Fuzes: I. Roof Tests on Yaw Machines; II. Field Tests at Corncake June 1 and June 7, 1943,* F. L. Mohler, Report OD-2-1, July 8, 1943. Div. 4-222.224-M18
37. *Revision of the MC-380 Circuit,* J. G. Hoffman, R. Stair, and A. Orden, Report OD-2-2, Oct. 1, 1943. Div. 4-238.1-M2
38. *Laboratory and Field Tests on RPEB-2 Fuze,* A. V. Astin and A. Orden, Report OD-2-3, Oct. 23, 1943. Div. 4-222.225-M4
39. *Probability of Sun Firing of M-2 Fuzes,* A. V. Astin, Report OD-2-4, Nov. 15, 1943. Div. 4-222.224-M25

[redacted]

40. *A Further Study of the Sun-Proof Modification of the MC-380 Fuze,* G. L. Scillian, R. F. Morrison, and J. G. Hoffman, Report OD-2-5, Nov. 22, 1943. Div. 4-247-M5
41. *Correlation of Laboratory and Field Tests of MC-380 Microphonic Rejects,* A. V. Astin and P. J. Franklin, Report OD-2-9, June 28, 1943. Div. 4-222.224-M14
42. *A Sun-Proof Modification of the MC-380 Fuze,* J. G. Hoffman, R. F. Morrison, and G. L. Scillian, Report OD-2-21, Sept. 4, 1943. Div. 4-247-M4

MEMORANDA OF THE ORDNANCE DEVELOPMENT DIVISION OF THE NATIONAL BUREAU OF STANDARDS

43. *Regarding Zero Stage Units,* Memorandum to J. E. Henderson from R. Hofstadter, Aug. 1, 1942. Div. 4-238.42-M1
44. *Firing PE Fuzes, Fort Fisher, August 6-9, 1942, Kite Target, North Range; Zero Stage Units; Ground Target on Beach; Radio Range,* Memorandum to J. E. Henderson from R. Hofstadter and J. F. Streib, Aug. 12, 1942. Div. 4-222.23-M3
45. *Progress Report No. 2 on Condenser Driven Single-Stage PE Unit,* Memorandum to J. E. Henderson from C. Ravitsky and D. Feldman, Dec. 14, 1942. Div. 4-212.3-M2
46. *Acceptance Tests of Westinghouse M1, 3¼-inch Rockets, Carrying M1 PE Fuzes at Aberdeen,* Memorandum to H. Diamond from L. S. Taylor, 425, Dec. 15, 1942. Div. 4-413-M3
47. *Report on Proving Ground Test of 12 Condenser-Powered PE Units Fired on the North Range, Fort Fisher, December 31, 1942,* Memorandum to J. E. Henderson from R. A. Becker and D. Feldman, Jan. 2, 1943. Div. 4-222.222-M1
48. *Zero Stage Units,* Memorandum to J. E. Henderson from R. Hofstadter and R. F. Morrison, Jan. 30, 1943.
49. *Status of Condenser Unit,* Memorandum to H. Diamond from A. V. Astin, Apr. 12, 1943. Div. 4-237-M1
50. *Trips to Aberdeen to Observe the Firing of PE and Radio Fuzes on Motors Loaded with HE,* Memorandum to A. V. Astin from F. L. Mohler, May 25, 1943. Div. 4-222.23-M6
51. *Further Observations on the Firing of M-2 and M-3 Fuzes on M-8 Projectiles at Aberdeen,* Memorandum to H. Diamond from T. B. Godfrey, May 25, 1943. Div. 4-222.223-M3
52. *Targets for MC-380 Units,* Memorandum to H. Diamond from A. V. Astin, July 3, 1943. Div. 4-618-M3

Chapter 9

1. *Rocket Targets as of November 1, 1941,* NDRC Report A-27, A. J. Dempster, Dec. 24, 1941. Div. 4-412.4-M1
2. *Rocket Flight Tests at Aberdeen,* NBS Report PG-48, Feb. 5, 1942. Div. 4-413-M1
3. *Flight Tests on 3.25-in. Rockets,* NBS Report PG-87, May 16, 1942. Div. 4-413-M2
4. *Tests of Miscellaneous Rocket Motors, May 31, 1942,* NBS Report PG-97, May 31, 1942. Div. 4-411.1-M3
5. *Preliminary Report on Tests of Cenco Rocket Motors Received June 12, 1942,* NBS Report PG-106. Div. 4-411.1-M4
6. *NBS Drawing 440R.* Div. 4-411.1-M1 or Div. 4-411.1-M2
7. *NBS II-5 Drawings A-30686, A-30688, and A-30697.* Div. 4-411.3-M1
8. *NBS II-5 Specification 1934.*
9. *NBS Drawings A-448, 443, 444, 447.* Div. 4-411.2-M1
10. *Field Test, Ballistics of T-25 Mortar Shells (MX-24), Blossom Point, October 29, 30, 31 and November 2, 1945,* G. Rabinow, Report OD-1-901, Nov. 29, 1945. Div. 4-511-M2
11. *Preliminary Ballistic Measurements on Mortar Shell, M43A1, Using Different Types of Fuzes,* L. M. Andrews, Report OD-4-46, Apr. 15, 1944. Also Supplement to OD-4-46, June 5, 1944. Div. 4-514-M1
12. *Wind Tunnel Tests on MRLG Units,* L. M. Andrews, Report OD-4-76, July 24, 1944. Div. 4-514-M2
13. *Summary of Wind Tunnel Ballistics of MRLG and MROG Fuzes on M43A1 Shells,* L. M. Andrews, Report OD-4-102, Apr. 2, 1945. Div. 4-513-M1
14. *Suggestion for the New 81-mm Mortar Shell,* L. M. Andrews, J. Rabinow, Report OD-4-103, Aug. 25, 1945. Div. 4-513-M2
15. *Ballistic Data on the T-25, Mortar Shell,* L. M. Andrews, Report OD-4-103, Supplement 1, Aug. 25, 1945. Div. 4-511-M1
16. *Effect of a Lighter Weight Fin Assembly on Stability of the M-56 and T-25 Mortar Shells,* L. M. Andrews, O. R. Cruzen, Report OD-4-103, Supplement 2, Nov. 21, 1945. Div. 4-513-M3
17. *Effect of Fin Shape on T-25 Mortar Ballistics,* L. M. Andrews, Report OD-4-103, Supplement 3, Dec. 17, 1945. Div. 4-513-M4
18. *T-25 Ballistic Data,* L. M. Andrews, Report OD-4-103, Supplement 4, Jan. 23, 1946. Div. 4-511-M4
19. *Physical Tests on T-25 Shell Sections,* L. Schuman, Report OD-4-103, Supplement 5, Dec. 26, 1945. Div. 4-511-M3
20. *The Magnetic Field Machine,* Jesse W. M. du Mond, NDRC Report A-8, p. 145, Figures 28, 29.
21. Letter (Re4a2) from Admiral W. H. P. Blandy to Dr. A. Ellett, Feb. 24, 1942.
22. *Radar Ranging on Anti-Aircraft Shell Bursts as of May 1, 1942,* NDRC Report A-68, R. D. Huntoon.
23. Memorandum to H. Diamond, Aug. 29, 1942, from R. D. Huntoon.
24. Report of A.A. Board on Project 22, "Radar Shell Burst Ranging," Sept. 23, 1942.
25. NDRC Report WA-33-2; report of J. Lawson.
26. NDRC Report WA-71-14; equipment GL3(X).
27. Intelligence Report, Serial 920, Naval Attaché at London, May 20, 1941.
28. Intelligence Report, Serial 213, Naval Attaché at London, Feb. 11, 1941.
29. ONI Report, Serial 256, N.A.A. London, Jan. 29, 1942.
30. BuOrd Letter S67(Re4a1), Dec. 19, 1941.
31. C.O. R.O.E. Letter DD418/S67/A5, Serial 01, Jan. 5, 1942.
32. Letter from Navy Department to Dr. R. C. Tolman, File No.(SC)S78-1(SONRD),Oct.24,1941. Div. 4-730-M2
33. Memorandum on Radar Ranging—Tests at Parris Island, S67(1047) Re4, Oct. 13, 1941. Div. 4-730-M1
34. Serial 920 N.A.A. London, May 20, 1941.
35. NDRC Report W-143-1, Section f.
36. *The Aerodynamics of Controlled-Trajectory Bombs,* H. L. Dryden, NDRC Report A-32, February 1942. Div. 4-242.11-M1
37. *Controlled-Trajectory Bombs as of March 1, 1942,* H. L. Dryden, March 1942. Div. 4-242.11-M2
38. *The State of Development of Maneuverable Controlled-Trajectory Bombs, as of September 1, 1942,* H. L. Dryden, October 1942. Div. 4-242.11-M3
39. *Treatments and Tests for Cotton Fabrics for Powder Bags,* Ralph T. Mease, NDRC Report A-72, July 1942. Div. 4-710-M3
40. *Development of Substitutes for Silk in Powder Bags,* Ralph T. Mease, NDRC Report A-32M, January 1942. Div. 4-710-M1
41. *Effect of Oxides of Nitrogen on Fabrics,* Ralph T. Mease, NDRC Report A-35M, June 1942. Div. 4-710-M2

DIVISION 4

Chief

Alexander Ellett

Technical Aides

A. S. Clarke
Sebastian Karrer
Cathryn Pike
John S. Rinehart
E. R. Shaeffer
A. G. Thomas
R. M. Zabel

Members

L. J. Briggs
W. D. Coolidge
Harry Diamond
F. L. Hovde
J. L. Tate

Special Assistants

M. G. Domsitz
W. E. Elliott
Wendell Gould
W. S. Hinman, Jr.
Joseph Kaufman
J. L. Thomas
E. A. Turner
F. C. Wood

Consultants

A. V. Astin
R. A. Becker
R. M. Bowie
Cledo Brunetti
J. W. DuMond
Saul Dushman
Wm. Fondiller
T. B. Godfrey
L. R. Hafstad
J. E. Henderson
R. D. Huntoon
J. A. Jacobs
R. B. Janes
T. Lauritsen
D. H. Loughridge
W. B. McLean
F. L. Mohler
S. H. Neddermeyer
H. F. Olsen
C. H. Page
W. J. Shackelton
F. B. Silsbee
K. D. Smith
G. W. Stewart
J. F. Streib
L. S. Taylor
G. W. Vinal
W. L. Whitson
R. M. Zabel

[redacted]

CONTRACT NUMBERS, CONTRACTORS, AND SUBJECTS OF CONTRACTS

The National Bureau of Standards, which served as the central laboratories for Division 4, NDRC, did not operate under a contract but as a government agency under a direct transfer of funds from OSRD.

Contract Number	*Name and Address of Contractor*	*Subject*
NDCrc–170	Western Electric Company New York, New York	Studies and experimental investigations in connection with the development of photoelectric devices.
NDCrc–195	Western Electric Company New York, New York	Studies and experimental investigations for the development of a magnetic instrument.
OEMsr–76	Western Electric Company New York, New York	Purchase of 200 photoelectric units.
OEMsr–99	General Electric Company Schenectady, New York	Studies and investigations on continuously adjustable time fuzes and associated equipment.
OEMsr–141	Radio Corporation of America Camden, New Jersey	Development and delivery of remote control equipment for aerial torpedoes.
OEMsr–145	Western Electric Company New York, New York	Studies and experimental investigation in connection with the development on photoelectric devices.
OEMsr–171	Radio Corporation of America Camden, New Jersey	Studies and experimental investigations for the development of television pickup units of improved sensitivity and report the results thereof.
NDCrc–173	Radio Corporation of America	Circuit development of new pickup tube.
OEMsr–255	Western Electric Company New York, New York	Studies and experimental investigations in connection with photoelectric devices.
OEMsr–258	Bendix Aviation Corporation Baltimore, Maryland	Studies and experimental investigations in connection with continuous development work on special radio devices.
OEMsr–298	Radio Corporation of America Camden, New Jersey	Supply certain television and related equipment.
OEMsr–343	Westinghouse Electric and Manufacturing Company Baltimore, Maryland	Studies and experimental investigations in connection with the development of special radio devices.
OEMsr–441	Radio Corporation of America Camden, New Jersey	Studies and experimental investigations in connection with the development of special electronic circuits and equipments.
OEMsr–476	Vidal Aircraft Company, Inc. Camden, New Jersey	Redesign and construction of gliders.
OEMsr–500	Western Electric Company New York, New York	Studies and experimental investigations in connection with the development of electronic devices.
OEMsr–501	Western Electric Company New York, New York	Purchase of 200 photoelectric units and 1,000 hytron tubes.
OEMsr–513	Radio Corporation of America Camden, New Jersey	Development of compact frequency modulation television equipment.
OEMsr–514	Radio Corporation of America Camden, New Jersey	Development of a new television jamming technique.
OEMsr–515	Radio Corporation of America Camden, New Jersey	Development of a more sensitive television pickup unit.
OEMsr–528	National Carbon Company New York, New York	Production of small batteries suitable for operation at low temperatures.
OEMsr–566	Raytheon Production Corp. Newton, Massachusetts	Studies and experimental investigations in connection with the development of miniature vacuum tubes.

Contract Number	*Name and Address of Contractor*	*Subject*
OEMsr-611	General Electric Company Schenectady, New York	Studies and experimental investigations in connection with the development of miniature vacuum tubes, and report the results thereof.
OEMsr-630	Sylvania Electric Products Salem, Massachusetts	Studies and experimental investigations in connection with the development of miniature vacuum tubes having a very low microphonic output.
OEMsr-769	University of Iowa Iowa City, Iowa	Studies and experimental investigations in connection with development work on special electronic devices and associated equipment.
OEMsr-866	Philco Corporation Philadelphia, Pennsylvania	Studies and experimental investigations in connection with the development of special radio devices and associated equipment.
OEMsr-885	Emerson Radio and Phonograph Corporation New York, New York	Studies and experimental investigations in connection with and carry on continuous development work on special radio devices and associated equipment.
OEMsr-887	Washington Institute of Technology Washington, D. C.	Development of accessories for special electronic devices and associated equipment.
OEMsr-905	Western Electric Company New York, New York	Studies and experimental investigations in connection with the development of special electronic devices.
OEMsr-939	Westinghouse Electric and Manufacturing Company Mansfield, Ohio	Studies and experimental investigations in connection with the development of illumination indicators.
OEMsr-941	Federal Telephone and Radio Corporation East Newark, New Jersey	Studies and experimental investigations in connection with the development of special selenium rectifiers.
OEMsr-949	University of Florida Gainesville, Florida	Conduct theoretical studies and experimental investigations in connection with problems peculiar to special electronic devices for ordnance application.
OEMsr-954	The Zell Corporation Baltimore, Maryland	Furnishing machining facilities in connection with development of special electronic devices.
OEMsr-980	Zenith Radio Corporation Chicago, Illinois	Studies and experimental investigations in connection with development of special electronic devices.
OEMsr-981	Knapp-Monarch Company St. Louis, Missouri	Studies and experimental investigations in connection with development of special power supplies and associated equipment.
OEMsr-1003	Radio Corporation of America Harrison, New Jersey	Studies and experimental investigations in connection with development of special miniature vacuum tubes.
OEMsr-1106	Westinghouse Electric and Manufacturing Company Washington, D. C.	Pilot production of special electronic devices.
OEMsr-1109	General Electric Company Schenectady, New York	Studies and experimental investigations in connection with development work on special electrical and radio devices and associated equipment.
OEMsr-1113	Emerson Radio and Phonograph Corporation New York, New York	Manufacture and delivery of special electronic devices.
OEMsr-1117	Globe-Union, Inc. Milwaukee, Wisconsin	Studies and experimental investigations in connection with development of special electrical and mechanical devices.
OEMsr-1133	Zenith Radio Corporation Chicago, Illinois	Manufacture and delivery of special electronic devices.

Contract Number	*Name and Address of Contractor*	*Subject*
OEMsr–1134	Knapp-Monarch Company St. Louis, Missouri	Manufacture and delivery of special power supplies.
OEMsr–1161	The Rudolph Wurlitzer Co. North Tonawanda, New York	Studies and experimental investigations in connection with the development of special electronic devices.
OEMsr–1163	The Rudolph Wurlitzer Co. North Tonawanda, New York	Manufacture and delivery of special electronic devices.
OEMsr–1196	Philco Corporation Philadelphia, Pennsylvania	Manufacture and delivery of special electronic devices.
OEMsr–1227	Bowen and Company, Inc. Bethesda, Maryland	Furnish necessary machine shop and assembly facilities for the development of special electronic devices.
OEMsr–1251	General Electric Company Schenectady, New York	Manufacture and delivery of special electronic devices.
OEMsr–1378	Raymond Engineering Laboratories Berlin, Connecticut	Studies and experimental investigations in connection with the development of special electronic devices.
OEMsr–1417	The Magnavox Company Fort Wayne, Indiana	Design toss bombing for production.
OEMsr–1437	The General Instrument Corp. Elizabeth, New Jersey	Studies and experimental investigations in connection with development of electronic and mechanical devices.
OEMsr–1477	Zenith Radio Corporation Chicago, Illinois	Development and production of special electronic devices.
OEMsr–1500	Emerson Radio and Phonograph Corporation New York, New York	
OEMsr–1501	Solar Aircraft, Inc. San Diego, California	Design and produce donut type setback arming devices for use on British rockets equipped with VT fuzes.

SERVICE PROJECT NUMBERS

The projects listed below were transmitted to the Executive Secretary, NDRC, from the War or Navy Department through either the War Department Liaison Officer for NDRC or the Office of Research and Inventions (formerly the Coordinator of Research and Development), Navy Department.

Service Project Number	*Subject*
Chemical Warfare Service	
CWS-19	Development of an influence fuze for airplane spray apparatus.
Army Air Forces	
AC-36	Controlled-trajectory bombs.
AC-62	Development of toss bombing equipment.
Navy	
NO-5	Development of substitute materials for silk powder bags.
NO-111	Radar ranging on shell bursts.
NO-115	Development of a radar homing bomb which homes on a target illuminated by radar, the illumination being provided either by the bomb-carrying plane or by other means.
NO-183	Development of toss bombing equipment.
Ordnance Department	
OD-27	Development of proximity (influence) fuzes for bombs and projectiles.
OD-33	Development of a fuze for use in bombardment flares, photoflash bombs, and fragmentation bombs.
OD-50 (Transferred to Section T April 18, 1942)	Development of the photoelectric type proximity fuze for use on AA shells.
OD-112	Development of toss bombing equipment and techniques.
OD-191	Development of VT fuze UHF and VHF circuit elements.
OD-192	Development of counter-countermeasures for VT fuzes.
Signal Corps	
SC-38	Field testing equipment for proximity fuzes.
SC-40	Substitute for dry battery BA-55.

INDEX

The subject indexes of all STR volumes are combined in a master index printed in a separate volume. For access to the index volume consult the Army or Navy Agency listed on the reverse of the half-title page.

[redacted]

[redacted]